AN INVESTIGATION OF

GRAND BATTEMENT DEVANT AT BARRE, CENTRE, AND IN MOTION

USING KINEMATICS AND ELECTROMYOGRAPHY

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This work or any part thereof has not previously been presented in any form to the University or to any other body whether for the purposes of assessment, publication or for any other purpose (unless otherwise indicated). Save for any express acknowledgments, references and/or bibliographies cited in the work, I confirm that the intellectual content of the work is the result of my own efforts and of no other person.

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ABSTRACT

The purpose of this study was to examine grand battement devant in three conditions: at the barre, in the centre, and traveling. The primary focus was to consider weight transfer in the three conditions, and to examine utilisation of the trunk and lower extremity muscles. An extensive review was done in the dance science literature to determine what previous research had been done related to this subject, and to establish what preliminary work might be needed. As indicated by the literature, in order to achieve this research, it was necessary to develop a dance-specific method for the normalisation of surface electromyography data. In phase one of the research, a dance-specific portable anchored dynamometer was developed and tested. The PAD allowed for the collection of maximum voluntary isometric contractions (MVICs), which could then be used to normalise the sEMG data. In phase two of the research, the grand battement was tested in the three conditions, at the barre, in the centre, and traveling. Forty female dancers volunteered (mean age 30.0 ± 13.0 yrs, mean height 1.63 ± 0.06 m, mean mass 59.0 ± 7.4 kg, and 13.9 ± 13.3 yrs of training in ballet and/or modern dance) and were placed in three groups (Training level): beginner (n = 12), intermediate (n = 14) and advanced (n = 14). Dancers executed five grand battement devant in each of the three conditions (Condition) in randomized order. Data were collected with a 7-camera Vicon motion capture system, two Kistler forceplates, and surface electromyography (EMG), using eight muscles bilaterally. Kinematic data were analysed in three intervals: stance to battement initiation, initiation to battement peak, and peak to end. Four variables were investigated: centre of gravity of the full trunk, centre of gravity of the pelvis, centre of gravity of the upper trunk, and centre of mass. EMG data were analysed in four events: stance, initiation, peak, and end. For weight transfer, the main effect of Condition was significant for all four variables in both the x-axis and the y-axis ($p < .001$). There were no significant differences for Training and no significant Condition x Training interactions. Muscle use varied according to the combination of event and condition that was executed, and these differences were also influenced by the level of training of the dancer and the side of the body used. It is recommended that dance educators consider the importance of allocating sufficient time to each of the three conditions (barre, centre, and traveling), to ensure development of a variety of motor strategies and muscle activation patterns for dance practice.

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CHAPTER ONE

INTRODUCTION

1.1 Background

For centuries, the understanding of dance movement has developed through observation, personal experience, and theoretical models. Respected educators (Lawson, 1984; Vaganova, 1969) summarized ideas about motor strategies and muscle activation based on traditional pedagogy that influenced the evolution of dance training and performance. By the early 1950s, dance inquiry began to involve the principles and techniques of biomechanics (Kneeland, 1966). Biomechanics is “the scientific discipline that studies the mechanical principles of human movement and provides information on muscular function and its characteristics” (Koutedakis, 2008, p. 73). It is this discipline and its applications to dance that have instigated the initiation of a transformation in how educators and practitioners understand dance movement.

Cinematography, kinematics, kinetics, and electromyography are the measurement tools within this discipline that can provide valuable insights into how dancers actually execute movement, and can determine comparisons between elite and novice dancers. By the 1970s, researchers started to use these tools to examine various aspects of dance movement. University researchers (Laws, 1978/79; Nichols, 1979; Ryman, 1978; Ryman & Ranney, 1978/79) conducted early innovative studies with rudimentary equipment and technology that would, by today’s standards, be considered tedious and cumbersome, and yet these researchers made landmark discoveries in the field of dance biomechanics and inspired generations of dance scientists to further the pursuit.

Dancers in classical ballet and contemporary dance train in a variety of conditions, including floor work, barre work, centre practice, and traveling. The barre has been the subject of dance research dating back to the late 1970s (Nichols, 1979; Ryman & Ranney, 1978/79). The biomechanical studies comparing work at the barre and in the centre suggest that dancers work differently in these two conditions (Nichols, 1979; Kadel & Couillandre, 2007; Sugano & Laws, 2002; Torres-Zavala, Henriksson, & Henriksson, 2005; Wieczorek, Casebolt, Lambert, & Kwon, 2007; Wilmerding, Heyward, King, Fiedler, Stidley, Pett, & Evans, 2001). Other noted researchers have hypothesized that there are differences between muscle activation and motor control strategies at the barre and in the centre (Ryman & Ranney, 1978/79; Laws, 1985; Woodruff, 1984).

It has long been assumed that there is positive transfer of training from the barre to centre work in dance training (Wilmerding & Krasnow, 2011). Looking to the motor control research, Cordo and Nashner (1982) found that when the participant leaned on a bar and performed arm movements disturbing equilibrium, the lower extremity and trunk postural reflexes did not respond. It is currently unknown if there is enough similarity between the muscular and biomechanical aspects of movement at the barre and centre to encourage positive transfer. If in fact there is dissimilarity and extensive time is spent at the barre, there may even be negative transfer, that is, barre work may be interfering with some aspects of dancing ability.

Other dance research has focused on the profiling of elite dancers, and comparisons between elite dancers and novice or non-dancers (Bronner, Brownstein, Worthen, & Ames, 2000; Bronner & Ojofeitimi, 2011; Chatfield, Krasnow, Herman, & Blessing, 2007; Krasnow, Chatfield, & Blessing, 2002; Kwon, Wilson, & Ryu, 2007; McNitt-Gray, Koff, & Hall, 1992; Monasterio, Chatfield, Jensen, & Barr, 1994; Mouchnino, Aurenty, Massion, & Pedotti, 1992; Nichols, 1979; Ojofeitimi, Bronner, Spriggs, & Brownstein, 2003; Sandow, Bronner, Spriggs, Bassile, & Rao, 2003; Spriggs, Bronner, Brownstein, & Ojofeitimi, 2002; Wilson, Lim, & Kwon, 2004). Differences between groups include variability of muscle use (Chatfield, Krasnow, Herman, & Blessing, 2007; Krasnow, Chatfield, & Blessing, 2002), anticipatory postural strategies (Monasterio, Chatfield, Jensen, & Barr, 1994; Mouchnino, Aurenty, Massion, & Pedotti, 1992), and muscle amplitude (Ferland, Gardener, & Lèbe-Néron, 1983; Wilson, Lim, & Kwon, 2004). Similarities between groups include reaction time in certain balancing tasks (Ojofeitimi, Bronner, Spriggs, & Brownstein, 2003) and responses to fatigue (Yoshida & Kuno-Mizumura, 2003). There is not sufficient research at this time to understand how elite dancers differ from novice dancers, and there is almost no research on the intermediate stage of dance training.

One of the questions raised by dance educators and somatic practitioners involves the issue of movement efficiency, and they propose the idea that elite dancers are more efficient in movement execution than novice dancers. However, there is insufficient research to date to clarify if this is the case, or even what efficiency would entail. Efficiency might suggest that elite dancers use less effort in the involved muscles, or it could mean that they use fewer muscles to achieve the task. For example, EMG studies of the plié have compared muscle use of advanced and beginning dancers (Ferland, Gardener, & Lèbe-Néron, 1983), ballet and modern dancers (Trepman, Gellman, Micheli, & De Luca, 1998; Trepman, Gellman, Solomon, Murthy, Micheli, & De Luca, 1994), and dancers with and without knee pain (Clippinger-Robertson, Hutton, Miller, & Nichols, 1986). Ferland, Gardener, and Lèbe-Néron (1983) concluded that advanced dancers had significantly lower biceps femoris activation at initiation of flexion and extension of demi plié than beginners, and they had significantly lower rectus femoris activation at the end of the flexion phase than the beginners. However, an intervention study by Couillandre, Lewton-Brain, and Portero (2008) revealed that the use of the biceps femoris increased post-training and was correlated with less ‘bucking’ in the spine during jumps.

While a variety of dance movements have been explored, the most recent literature review of dance biomechanics studies (Krasnow, Wilmerding, Stecyk, Wyon, & Koutedakis, 2011) has identified the grand battement as the subject of one the earliest biomechanics investigations in the dance literature. Although Ryman and Ranney (1978/79) collected data on the grand battement devant only in the unsupported condition, they discussed their observations of dancers at the barre, claiming that there is less weight shift to the supporting leg during the battement at the barre than in the centre. Similarly, Laws (1985) proposed that the barre allows for forward shift of the torso in arabesque and provides torso stabilization for movements such as rond de jambe that are not possible without the barre; he questioned whether this work is transferrable to centre practice. A recent investigation by Bronner and Ojofeitimi (2011) did extensive descriptions for elite dancers executing grand battement devant, à la seconde and derrière, and found large pelvic movements in all three planes to accommodate hip joint movement. However, there is no comparative data in the centre, and therefore it is not possible to know if elite dancers perform these movements with similar strategies when unsupported.

In summary, the dance research to date suggests the following: (a) there are important differences between several aspects of movement execution with and without a barre, including weight shift strategies, muscle activation, joint torque, and dynamic alignment; (b) dancers rely on the barre in some aspects of movement organization regardless of level of training; (c) the action of weight transfer in movement execution may be an area of particular concern, since this is such a crucial aspect of biomechanical and muscular organization in dance; and (d) there is high variability in muscle activation when comparing barre work and centre practice, and when comparing dancers of various levels of training. To date, no dance research has compared barre and centre work to dance movement traveling in space, and determined whether this third condition is biomechanically different from the other two.

If dance educators are to be optimally effective in preparing dancers for the performance of dance repertoire, it would be useful to understand what aspects of training are transferrable from barre to centre and from centre to travelling, and in what ways elite dancers differ from novice dancers. Similarly, medical practitioners working in the field of dance injury rehabilitation could benefit from this knowledge and improve strategies for preparing dancers to return to full function.

1.2 Purpose

The purpose of this study was to examine grand battement devant in three conditions: at the barre, in the centre, and traveling. The first hypothesis was that weight shift in the three conditions (that is, transfer of weight from two feet to one foot for the barre and centre conditions, and from one foot to the other foot in traveling), would differ significantly during the three conditions. The second hypothesis was that weight shift in the three conditions would differ significantly between dancers of various training levels. The third hypothesis was that utilisation of the trunk and lower extremity muscles would differ significantly during the three conditions. The fourth hypothesis was that utilisation of the trunk and lower extremity muscles would differ significantly between dancers of various training levels.

In order to test these hypotheses, a dance-specific portable anchored dynamometer (PAD) was developed. In a recent review of dance biomechanics research (Krasnow, Wilmerding, Stecyk, Wyon, & Koutedakis, 2011), 21 studies reported EMG data collection, but less than half of these used some system of determining maximum voluntary contractions (MVCs) or maximum voluntary isometric contractions (MVICs) for the participants. There is no standardized method used in dance EMG studies to normalize data across participants, so that muscle amplitudes can be compared. In order for this study to compare muscle amplitudes across subjects, normalisation of EMG data was necessary, and therefore, the development of the dance specific PAD was crucial to the purposes of this study.

CHAPTER TWO

REVIEW OF LITERATURE

[a version of this chapter has been published in *Medical Problems of Performing Artists*]

Krasnow, D., Wilmerding, M. V., Stecyk, S., Wyon, M., & Koutedakis, Y. (2011). Biomechanical research in dance: A literature review. *Medical Problems of Performing Artists, 26*(1), pp. 3-23.

2.1 Review Methodology

The components of this study required a review of the biomechanics research studies involving dancers. To find relevant articles for the current review, the investigation used search engines, including PubMed and Web of Science, five previous review articles (Brink, 1991/92; Bronner & Spriggs, 2003; Minton, 2000; Ranney, 1988; Wilson & Kwon, 2009), the *Dance Medicine and Science Bibliography* (Solomon & Solomon, 2005), and the reference lists of theses, dissertations, and articles being reviewed. Any dance research articles involving the use of electromyography (EMG), forceplates, motion analysis using cinematography or videography, and/or physics analysis were initially included. In order to ensure the broadest scope in looking at the current literature, no exclusion criteria were employed, other than restricting the review to English language articles. Since many research studies in dance are presented at conferences and represented by abstracts or brief summaries, these short descriptions have also been reviewed, despite lacking some of the necessary information for a complete understanding of the work. Finally, a small number of theoretical articles have been included due to their perspective on biomechanical research and methods of analysis. Articles for the literature review were then limited to those having direct relevance to the focus of this study. Articles have been grouped based on the movement concept or specialized movements being studied: alignment, plié, relevé, passé, degagé, développé, rond de jambe, grand battement, forward stepping, turns, elevation work, and dance-specific motor strategies. Although there is some overlap in the categories, this method of grouping the articles provided the most provocative insights. Within each group, articles will be discussed chronologically, to emphasize the development of the technology over time. This review concludes with an overview of potential limitations in biomechanics research methodologies to date, and questions that arise from the body of research studies currently available.

2.2 Review of Articles Based on Dance Movement

2.2.1 Alignment.

Although researchers and educators have varying definitions of alignment, the most common is based on the arrangement of the body segments and skeletal structure in a vertical column with respect to the line of gravity.

Nichols (1979) examined deviations in verticality in the upper spine, lower spine and total spine, and what effects these deviations had on how dancers executed the grand plié. Additionally, she considered the influence of the use of the ballet barre and dance experience. There were a total of 28 participants in the study, divided into four equal groups: 21 female undergraduate students with no dance experience divided into three groups based on the ratio of upper spine length to total spine length, and 7 additional advanced ballet students. Coincidentally, the ballet dancers all had spine ratios similar to the middle group of non-dancers. Participants were filmed from a side view with a Vanguard Motion Analyser, with five white circles placed on the body as landmarks. They executed five grand pliés with and without the barre. Analysis was a 4 X 2 X 5 ANOVA with variables defined by various spinal deviations from vertical as the dependent variable, and experience levels, barre/no barre, and various positions for the plié as the independent variables. Results indicated that spinal ratio had no effect upon alignment deviations. Verticality of the spine was not related to experience, but experience did influence consistency in the task. Further, lack of flexibility was also an issue in consistency of movement. Finally, at the deepest moment of the plié, there were reductions in alignment deviations when using the barre but not without the barre, even in the experienced dancers.

Krasnow, Chatfield, Barr, Jensen, and Dufek (1997), conducted an intervention study, measuring both static and dynamic alignment using the Peak 5 Clinical and Research Video System. Data were collected with a single camera, using 8 reflective markers along the right side of the body. A plumb line was suspended from the ceiling in camera view to ensure vertical accuracy. The participants were 20 university dance students, divided into four groups: conditioning only, imagery only, conditioning with imagery, and controls. Participants performed six trials of the grand plié in first position turned out, three from static stance and self-paced, and three with an off-centre torso movement preceding the plié with music. Participants were pre- and post-tested, with 8 weeks of intervention. Analysis consisted of 4 X 2 X 2 (group by time by condition) ANOVA. All participants improved from pre- to post-testing, which is not surprising given that all were participating in ongoing dance training. Additionally, participants in all four groups demonstrated significantly larger scores (markers further from the plumb line) in Condition 2, the condition in which the off-centre torso movement preceded the plié. When looking at different moments during the plié, it was further discovered that the group who did conditioning with imagery showed the greatest improvement from pre- to post-testing at the moment between the end of the off-centre torso movement and the return to vertical to start the grand plié. This result indicates that they were able to find better alignment more quickly in a dynamic situation than the other groups after the intervention. In addition to supporting a combined use of conditioning and imagery for improving alignment, the researchers also concluded that it is essential to study alignment in dynamic rather than static conditions.

Wilmerding, Gurney, and Torres (2003) assessed the degree and magnitude of changes in the angle of pelvic tilt in young dancers training in Flamenco dance. Data were collected with a Vicon motion analysis system with multiple reflective markers on the lower extremities and pelvis. Participants were 10 girls and 6 boys between the ages of 4 and 12 years old who had trained in Flamenco dance. Data were collected in the following two conditions: (1) standing barefoot and feet flat on the floor, and (2) standing barefoot with heels on a two-inch platform, to simulate the use of the standard Flamenco shoe. Analysis consisted of t-tests. There were no significant differences in left and right sides, and no differences based on age, height, or gender. There was a significant change in the angle of plantar flexion when participants were on the platform. Variance in hip, knee and pelvis angles did not correlate with ankle changes. Individual strategies may account for the lack of significant change in pelvic tilt, as some dancers used anterior pelvic tilt while others used posterior pelvic tilt to compensate for the elevation of the platform.

2.2.2 Plié.

Ferland, Gardener, and Lèbe-Néron (1983) were interested in comparing dancers at different levels performing demi pliés, looking at EMG activity of the rectus femoris and bicep femoris. This article was a short abstract, and therefore, not all information was reported. Participants (total number not stated) were adult females studying classical ballet or modern dance, and were divided into three groups, beginner, intermediate and advanced. In addition to the EMG data collection, participants were filmed. While not explicitly stated, the researchers used some method to determine each participant's maximum contraction for these two muscles, making it possible to compare EMG amplitudes of trial means. The researchers concluded that advanced dancers had significantly lower biceps femoris activation at initiation of flexion and extension than the other two groups, and they had significantly lower rectus femoris activation at the end of the flexion phase than the beginners. They suggest that training may result in more efficient use of muscles around the hip and knee in this activity.

Woodruff (1984) investigated the grand plié performed in first and second position at the barre. This study had one participant, an elite ballet dancer, and Woodruff acknowledges that the results cannot necessarily be generalized. No details are given regarding number of trials. Data were collected using motion analysis, but there is no specific description. Analysis was a descriptive discussion of centre of gravity (CoG) displacements. In first position there was minimal CoG displacement, but in second position, there was a large CoG displacement towards the barre. There was an unexpected ankle pattern during the first position plié, consisting of flexion, slight extension, followed by flexion again. The highest muscular moments occurred in second, suggesting that this position requires greater strength than first position, and that second position may create greater stress on the knee.

Clippinger-Robertson, Hutton, Miller, and Nichols (1986) also investigated the second position grand plié, using both cinematography and electromyography. Fourteen participants were selected, and matched according to level and type of dance studied. All were intermediate to professional ballet or modern dancers. Participants were filmed, and analysis using graphs and measurements was done at 30º, 60º, 90º and full knee flexion. EMG electrodes were placed on vastus medialis, biceps femoris, and adductor longus. The number of pliés performed is not stated. Cinematography revealed that there was a trend for dancers with chondromalacia to incline the trunk forward and tilt the pelvis anteriorly, not seen in matched participants without chondromalacia. EMG data suggested that dancers with chondromalacia utilize greater muscle amplitudes overall, and in particular there is quadriceps dominance. There is no discussion of how amplitudes were compared, or if maximum contractions were determined. The researchers also note the great individual variability in muscle use, even in matched participants, and the plasticity of the participants' motor patterns, when given a variety of cues and feedback.

Trepman, Gellman, Solomon, Murthy, Micheli, and De Luca (1994) examined standing posture and the demi plié, using electromyography and videotape. Participants were five ballet and seven modern professional female dancers.

Electrodes were placed on the right leg on the following muscles: lateral gastrocnemius, medial gastrocnemius, tibialis anterior, vastus lateralis, vastus medialis, gluteus maximus, hamstrings, and hip adductors. For the standing data collection, participants were recorded in first position three times for a 4-second period. Pliés were performed five times in first position, over a 6-second period. Various joint angles were determined from the videotape using a goniometer. Analysis was performed for average values using t-tests, chi-square test, and a two-way ANOVA for height and joint range of motion against time. In order to compare participants' EMG data, and to create individual and group averages, the researchers observed peaks and valleys in the normalized EMG graphs to define minimum and maximum values. This procedure is fairly unique in the literature, and an interesting variation from the use of maximum voluntary contractions (either concentric or isometric) seen in the sports literature. For standing posture, muscles were graded as having either baseline activity throughout the trial, or activity above baseline. When all dancers were considered together, EMG activity above baseline was seen most frequently in medial gastrocnemius (greater in the ballet dancers) and tibialis anterior (greater in the modern dancers). For the demi plié, the ballet dancers demonstrated significantly more activity than the modern dancers in four of the eight muscles tested: lateral gastrocnemius, medial gastrocnemius, gluteus maximus and hip adductors, in various phases of the plié. At the end of the plié there was significantly more activity in the quadriceps of the ballet dancers, which the researchers suggested was due to genu recurvatum and the classical aesthetics. Additionally there was considerable variation between individuals, regardless of training.

Trepman, Gellman, Micheli, and De Luca (1998) wrote a second article on the data collected from the above study, looking at the grand plié in first position. The results support the idea that muscle activity can be described in three categories: (1) muscle activity required for execution of the movement, (2) muscle activity differentiated based on dance idiom or form being studied, and (3) muscle activity that is individual, based on factors such as body characteristics, motor strategies, balance, and individual training. One of the striking observations in the analysis of the muscle use in the grand plié is that it is not simply a deepening of the demi plié, but rather a distinct movement using different muscles, and may therefore be essential to dance training.

Barnes, Krasnow, Tupling, and Thomas (2000) investigated external longitudinal rotation (ELR) at the knee in the execution of grand pliés in second, third, and fourth positions. Participants were 10 professional female ballet dancers, who performed three grand pliés and one demi plié in each position. Data were collected using two video cameras and the Ariel Performance Analysis System, with multiple markers placed on seven lower leg segments. Analysis consisted of an ANOVA on one randomly selected trial per position. Results demonstrated that ELR values are highest at the bottom of the movement in all positions, and that third and fourth position yield higher overall ELR values than second position throughout the movement. The researchers suggest limiting excessive repetition of grand pliés, particularly in third and fourth positions.

Couillandre, Lewton-Brain, and Portero (2008) conducted an intervention study involving the demi plié, using mental imagery to affect muscle use and movement strategies. EMG data were collected on four lower limb muscles: vastus lateralis, biceps femoris, tibialis anterior, and soleus. Additionally, a muscle tester and accelerometer were used, and measurements at the lateral knee were collected with a goniometer. Participants were seven female professional ballet dancers, who were pre- and post-tested performing movement in two conditions: (1) a free-standing first position demi plié, and (2) a jump in first position. The intervention consisted of biomechanical and anatomical explanations of the movements, followed by mental imagery techniques designed to encourage better alignment, more efficient muscle recruitment, and improved movement function. Analysis consisted of a paired t-test if normality passed, and a Wilcoxon Signed Rank test if normality failed. For the demi plié, there was no significant difference in maximum knee flexion after the intervention. There was a significant difference in biceps femoris activity, which was more active after the intervention. For the jump condition, there was no significant difference in height of the jump or maximal vertical acceleration after intervention. The biceps femoris activity increased, especially in the lowering phase before the jump, and an increase in tibialis anterior activity in the ascending phase before the jump, along with a decrease in vastus lateralis activity. Sagittal variation (”bucking” in the spine) was reduced post intervention.

2.2.3 Relevé.

Albers, Hu, McPoil, and Cornwall (1992/93) investigated foot plantar pressures in a variety of conditions. Participants were 10 female ballet students who performed three trials of each of the following: (1) self-paced walking barefoot, (2) self-paced walking in pointe shoes (3) elevé en pointe (from straight legs in second position to full rise), (4) relevé (a forward step, followed by plié-relevé en pointe) onto the dominant leg. The order of the last two was randomized. Trials were done on a forceplate and a ten-meter walkway. Analysis consisted of taking the mean of the three trials for each condition, and then performing within-subjects ANOVA, followed by Tukey's post-hoc comparisons. There was a significant difference between walking barefoot and the other three conditions, and between walking in shoes and the relevé condition.

Yoshida and Kuno-Mizumura (2003) examined the effect of fatigue on a relevé test, through EMG analysis. Electrodes were placed on the medial gastrocnemius, lateral gastrocnemius, soleus, and tibialis anterior. Participants were six female Japanese dance students and seven Japanese females with no dance experience. As this paper was a conference abstract, information was limited. There is no indication that maximum contractions for the muscles in question were determined, nor is the method of analysis described. All participants performed the relevé to exhaustion. There was no significant difference between the two groups in number of relevés performed. Dancers had greater range of motion at the ankle, and the concentric phase showed an increase in EMG activity of all muscles in dancers. The researchers state that the soleus is more fatigue resistant in dancers, and that these differences may be the result of training.

Massó, Germán, Rey, Costa, Romero, and Guitart (2004) conducted a study of muscle activity during relevé, comparing parallel and externally rotated positions. Data were collected with a four-camera Elite Motion Analyser system and electromyography recording the following muscles: peroneus longus, soleus, lateral gastrocnemius, medial gastrocnemius, and abductor hallucis. Participants were 18 female professional ballet dancers who performed the following movements: relevé in parallel (sixth position), relevé in first position turned out, and relevé in first position turned out “without any active muscular control and with foot pronation” (p. 102). Number of trials per condition was not reported. For analysis, means and standard deviations were computed. Intra-subject comparisons were made using the Wilcoxon test, and EMG data were analysed through direct observation. No maximum contractions were collected, and no statistical analysis was performed on EMG data. Results indicate the following: plantar flexion angle was statistically higher in sixth position than in first; medial gastrocnemius is more active in relevé in first position, but the abductor hallucis is more active in sixth position; with foot pronation, peroneus longus and gastrocnemius muscles were most active.

Kadel, Donaldson-Fletcher, Segal, Falicov, and Orendurff (2004) investigated muscle activity during four movements en pointe: rise to demi pointe, elevé (rise to full pointe from straight legs), piqué passé (stepping onto one foot en pointe), and a two-foot spring to pointe. Data were collected with electromyography, motion analysis using a ten-camera Vicon system and 38 reflective markers, and two forceplates. Electrodes were placed on the medial gastrocnemius, lateral soleus, peroneals, and tibialis anterior. Four female professional ballet dancers performed three trials of each condition, standing with one foot on each forceplate. Data were analysed in Polygon, and trials were averaged, with maxima and minima recorded. Results indicate the following: plantar flexion is greatest following the elevé rather than the other conditions; muscle activity for all four muscles was greatest during the rise to pointe, but decreased once the dancer arrived en pointe; soleus activity was low during the rise to demi pointe, but during the rise to full pointe was similar to its activity for the piqué and the spring to pointe.

A similar study by Kadel and Couillandre (2007) was reported in an abstract for a conference presentation. Their purpose was to compare joint angles, moments, and muscle activity during three movements en pointe: rise to pointe in 2nd position, pique retiré (stepping onto one foot en pointe), and a two-foot spring to pointe. Data were collected with electromyography, motion analysis using a 10-camera Vicon system and 38 reflective markers, and two forceplates. Electrodes were placed on the stance leg on the medial gastrocnemius, lateral gastrocnemius, soleus, peroneals, and the tibialis anterior. Sixteen female professional ballet dancers stood with one foot on each forceplate and performed three trials of each of the three movements in two conditions, supported and unsupported. The order of the trials was randomized. Analysis consisted of t-tests, and the results indicated that there was no significant difference in maximal plantar flexion angle between supported and unsupported conditions for the three movements. Muscle use at the barre was significantly different for most of the muscles tested than without the barre. For soleus and tibialis anterior, there was more activity at the barre, but for peroneals and medial gastrocnemius there was less activity at the barre.

Bartolomeo, Sette, Sloten, and Albisetti (2007) reported their research in a conference poster presentation, and not all information is presented. They collected EMG data on the tibialis anterior, medial gastrocnemius, and rectus femoris for 101 male and female ballet and modern dancers performing relevé on demi pointe and pointe. Data were evaluated using the normalized ARV (average rectified value) index. There is no report of maximum contractions being collected. The researchers state that demi and full pointe have different muscle activation patterns, and there are also gender-based and individual differences, but no statistical analysis was done, and no other conclusions were stated.

2.2.4 Passé.

Bronner and Brownstein (1998) conducted this first study looking at the passé, with the goal of providing normative data in skilled dancers for this multi-joint movement requiring stability and balance. Data were collected with a two-camera motion analysis system and 12 reflective markers. Participants, five male and five female professional dancers, performed the movement in two conditions: (1) a series of six consecutive passé movements with each leg, and (2) a series of 12 passé movements alternating legs. The entire process was executed two times. Analysis consisted of measurements of temporal sequencing, marker displacements, and various velocities of trunk and limb markers. Results indicated that dancers are consistent in their execution of the task, and that trunk translation precedes limb activity.

Sandow, Bronner, Spriggs, Bassile and Rao (2003) compared expert dancers and beginners executing the passé from bipedal stance, reported in a conference abstract. Data were collected with a five-camera motion analysis system; no other information about the system was reported. The participants, 10 elite female dancers and 10 female novice dancers performed five trials of the movement, all with the right leg as the gesture leg. Means and coefficients of variation for each individual were calculated over the five trials, and grand means and standard deviations were calculated for each group. Results suggest that the elite dancers are more consistent in temporal and spatial elements than the beginners. The elite dancers were able to maintain unilateral balance for a longer period of time, and demonstrated anticipatory postural control not seen in the beginners.

Bronner and Ojofeitimi (2006) examined gender and limb differences in the execution of the passé. Data were collected with a one-camera Peak Performance motion analysis system, and twelve reflective markers placed bilaterally on the trunk and limbs. A power analysis was conducted, indicating the minimum participant number was six. Six male and six female professional ballet and modern dancers executed six consecutive passé movements from turned out first position with the right leg, and six with the left leg. The entire sequence was repeated. Each passé sequence was approximately 1.2 seconds. Analysis consisted of interclass correlation coefficients, calculations of means and standard deviations, and two types of 2 X 2 ANOVA – between (gender) and within (limb). The latter looked at both right versus left, and preferred versus non-preferred. Results indicated no limb differences. Gender differences were identified in peak hip angular displacement, with women demonstrating greater hip flexion than men. Overall, there was similar coordination in males and females, and in limbs, most likely due to extensive, symmetrical training of a highly specific task.

2.2.5 Degagé.

Mouchnino, Aurenty, Massion, and Pedotti (1992) compared the degagé à la seconde in experienced dancers and naïve participants. Data were collected with a one-camera Elite motion analysis system and 14 reflective markers on the trunk and lower limbs, one forceplate, and EMG electrodes placed on the erector spinae, rectus abdominus, gluteus maximus, tensor fasciae latae, vastus lateralis and vastus medialis (paired), biceps femoris, lateral and medial gastrocnemius and soleus (grouped), and tibialis anterior and lateral peroneals (grouped). Fourteen male and female volunteers were divided into two groups: five experienced modern dancers, and nine naïve participants. Participants performed four degagés with each leg as fast as possible. In the first paradigm, they were given no instructions regarding the trunk; in the second paradigm, four naïve participants were asked to keep the trunk as vertical as possible. Analysis consisted of t-tests for both paired variables and two populations. Results indicated several differences between experienced dancers and naïve participants. Dancers exhibited no adjustment phase, whereas the naïve participants had a long adjustment phase, the period of time between the initiation of the gesture, and arrival on balance on the supporting leg. Dancers had a feed forward strategy, with muscles of the supporting leg activating prior to the gesture leg muscles; the strategy of the naïve participants was reactionary. Dancers used a translation strategy in the pelvis to shift the centre of weight over to the supporting leg; naïve participants used an inclination strategy and tilted the pelvis to achieve weight transfer. It is suggested that training may be responsible for altered strategies in experienced dancers.

Lepelley, Thullier, Koral, and Lestienne (2006) conducted a study investigating what they call the jeté, which is normally terminology for the leap, an elevation step. However, they only analysed the forward brushing action of the leap from first position turned out, and then returning to first position, which more closely resembles the action of a degagé. Data were collected using a four-camera Vicon motion analysis system, with 17 reflective markers. EMG activity was collected on eighteen muscles as follows: electrodes were placed on both legs on the biceps femoris, rectus femoris, vastus lateralis, vastus medialis, tibialis anterior, lateral gastrocnemius, soleus, and on trunk and pelvis muscles on left or right side in different participants on lumbar extensors, rectus abdominus, psoas, and gluteus maximus. For EMG analysis, researchers used percentage of dynamic maximum during trials. Participants were six female ballet dancers, four advanced students and two professionals. They performed ten trials of the task, with the right leg. A major finding was that the EMG activity of several of the muscles was minimized just before initiation of the trial, and at the start of the reversal phase. The researchers offer suggestions for controlling multi-muscle and multi-joint systems in dance.

Wieczorek, Casebolt, Lambert, and Kwon (2007) investigated knee mechanics during degagé à la seconde at barre and centre, and looked at the standing knee from three spatial perspectives. Data were collected on one female professional dancer with a 3-D motion analysis system using 30 reflective markers, and two forceplates, with each foot positioned on a different forceplate. The participant performed two trials of a degagé à la seconde in each condition, with and without use of the barre; only the second trial was used for analysis. Analysis was a three-dimensional inverse dynamics approach used to calculate resultant joint movements for the supporting (left) leg. Results indicate that different strategies are used for the degagé when performed with and without a barre. The researchers suggest that there is hamstring co-contraction at the supporting knee without the barre that is not present when the barre is used. Amount of torque at the supporting knee was less without the barre for support.

2.2.6 Développé.

Monasterio, Chatfield, Jensen, and Barr (1994) did a follow-up investigation to the work by Mouchnino et al. (1992), examining differences between trained dancers and non-dancers performing a low développé à la seconde starting at the ankle and ending just off the floor. Data were collected with a two-camera Watsmart 3-D motion analysis system, reflective markers on eight locations. Fourteen EMG electrodes were placed bilaterally on medial hamstrings, vastus medialis, erector spinae, lower abdominals, trapezius and lower sternocleidomastoideus, and on the right (stance) leg only on the gastrocnemius and tibialis anterior. Participants were 10 intermediate college dancers with ballet and modern training, and 10 non-dancers in the same age group. Ten trials were executed in each of three conditions, all with the left leg as the gesture leg: slow speed, self-paced speed, and fast speed. Analysis was a 2 X 4 X 10 ANOVA (group by muscle by trials). Results indicated that postural muscle activity (hamstrings, quadriceps, tibialis anterior and gastrocnemius) occurred prior to the voluntary movement in the dancers, in the fast trials only. Kinematic data was inconclusive.

Bronner, Brownstein, Worthen, and Ames (2000) compared various levels of dancers executing arabesque. This article was a conference abstract, and there is not extensive detail. Data were collected using a 3-D motion analysis system. Thirty participants were divided evenly into three groups: professionals (minimum of 10 years of dance training), advanced, and beginner-intermediate, based on ballet placement by faculty at an international dance school. No information is given about methods or analysis. Results suggest that frontal plane postural control and execution of the transitions between movement phases varied greatly from expert to student dancer. Students appeared to focus more on the gesture limb, at the exclusion of trunk control and smooth execution.

Wilmerding, Heyward, King, Fiedler, Stidley, Pett, and Evans (2001) compared muscle use during the développé devant from fifth position at barre and in the centre. EMG data were collected on the vastus lateralis and hamstrings of the gesture leg, and on the abductor hallucis and tibialis anterior of the standing leg. Maximum isometric voluntary contractions were collected on each muscle for use during analysis. Participants, 18 professional and advanced female dancers, performed five trials in each condition (barre and centre), in random order. Analysis was a mixed-effects four factor ANOVA, followed by Tukey’s post hoc tests. Results indicated that the standing leg muscles showed the greatest variance between conditions. Activity of the abductor hallucis and tibialis anterior for the standing leg was significantly greater in the centre than at the barre, suggesting that postural responses for balance may not be well trained at the barre.

An abstract submitted to the International Association for Dance Medicine & Science’s Annual Meeting by Spriggs, Bronner, Brownstein, and Ojofeitimi (2002) describes an investigation of variations in movement smoothness between groups of various levels performing arabesque. Data were collected using a Vicon five-camera motion analysis system. Thirty male and female participants were divided into three groups: beginner, advanced, and expert. 2D and 3D “cost jerk” (defined as rate of change of acceleration) was determined for comparison across groups. There is no information about number of trials. Results indicated a reduction in values from beginner to expert, suggesting that increased “smoothness” develops with higher levels of training.

Feipel, Dalenne, Dugailly, Salvia, and Rooze (2004) focused on the lumbar spine, during execution of arabesque, développé à la seconde with and without barre, and pied-en-main at the barre, in which the gesture foot is held by the ipsilateral hand and lifted as high as possible. Participants were 25 professional or semi-professional ballet dancers, 17 female and 8 male. Each movement began from turned out first position, and was executed three times on each side. Data were collected with a Spine Motion Analyser mounted on the dancer using straps at the thorax and pelvis, and photography. Dancers also completed a questionnaire about dance and medical history. Analysis consisted of Kruskal-Wallis median ANOVA and Wilcoxon matched pairs test. Results indicated that pain and injury in the lumbar area significantly affected shoulder inclination during développé à la seconde with and without barre, and pied-en-main at the barre. However, there was no correlation between posture and lumbar motion during the tasks. The researchers conclude that height of the leg in all of the dance movements examined depends more on hip flexibility than a spine contribution.

Torres-Zavala, Henriksson, and Henriksson (2005) also examined developpé à la seconde with and without the barre. Data were collected with an eight-camera Elite motion analysis system, using 22 reflective markers, and two forceplates. Twelve professional ballet dancers (10 women and 2 men) performed five trials in each of the two conditions, with and without the barre, and completed a questionnaire. In this abstract, little information is given about analysis. Results indicated that centre of pressure displacement was different in the two conditions, and that barre may impede the development of correct postural control for this task.

2.2.7 Rond de jambe.

Thullier and Moufti (2004) examined the multi-joint coordination of rond de jambe, performed just off the floor. Data were collected with a four-camera Vicon motion analysis system, using 17 reflective markers. Participants were six elite classical dancers (experts) and six gymnasts with no dance training. Participants executed the movement ten times. Analysis included Mann-Whitney U tests. The researchers concluded that although both groups were equally stable, dancers were more successful in accurately representing the shape and spatial orientation of the movement. They also stated that there are underlying rules or patterns in the nervous system's ability to integrate multiple degrees of freedom, that is, to master and execute multi-joint coordination.

Wilson, Lim, and Kwon (2004) profiled the grand rond de jambe en l'air en dehors (front to back), and compared skilled versus novice ballet dancers. Data were collected using six digital Panasonic camcorders, with 11 reflective markers, and digitized using the Kwon3D software. Ten university dance students were divided into two equal groups, identified as skilled or beginner by two ballet faculty members. Participants executed three trials of the movement, instructed to keep the gesture leg (right) at a 90º angle from the standing leg and torso. The best trial, determined by consistency of height and stability, was selected for analysis. Formulas were computed, including pelvic and trunk motions, and analysed using t-tests for comparing the two groups. There were significant differences in vertical angle of the gesture leg (skilled dancers' gesture legs were above 90º and beginners below), and pelvic tilt (skilled dancers demonstrated more pelvic motions than beginners), but no significant differences in trunk motions were found. It was concluded that skilled dancers use a pelvic strategy to execute this dance movement.

Kwon, Wilson, and Ryu (2007) conducted a further investigation of the gesture and stance legs in grand rond de jambe en l’air en dehors. Data collection included six digital Panasonic camcorders, multiple reflective markers, the Kwon3D software for digitizing, and a forceplate for ground reaction forces. Participants, eight skilled and eight novice female ballet dancers, performed the grand rond de jambe in two conditions set to music: at 90º and at 105º. Standard inverse dynamics procedures were used to compute hip net joint moments, and normalized to each participant’s mass. Analysis was a two-way, mixed-design ANOVA, and post-hoc comparisons of the group means were performed with the Sidak adjustment. The researchers concluded that muscular strength, especially in the gesture leg, is not what prevents the beginners from using the strategy of the skilled dancers. A second observation was that increased demand (vertical leg angle) actually puts less demand on the hip muscles of standing leg. Finally, the hip abductors were identified as highly important in the execution of this task. The researchers recommend placing more emphasis on the standing leg in the training process.

2.2.8 Grand battement.

Ryman and Ranney (1978-9) examined the grand battement devant performed unsupported, that is, without use of the barre. While many educators and researchers discuss this study as a comparison between executing this movement with and without the barre, no trials were performed or analysed using the barre. Data were collected with single-camera cinematography, recording the movement with markers and fins on the dancers' bodies, forceplates, and EMG electrodes placed on the rectus femoris, vastus medialis, gluteus maximus, biceps femoris, sacrospinalis, and rectus abdominus. Participants were four female advanced ballet dancers from an internationally recognized professional school. Dancers executed three trials of the grand battement, and the middle trial was used for analysis. Data for MVCs (maximum voluntary contractions) were also collected for EMG analysis purposes. The film was viewed on a Numonics Analyser to determine body segment displacements, and all analysis was descriptive. The researchers suggest that many of the suppositions dance educators make in teaching this movement are not supported by the results of this study. The gesture knee slightly flexes and the leg loses contact with the floor early in movement initiation. The pelvis rotates (posterior tilt), the lumbar spine flexes, and turnout is not maintained in the gesture leg, most likely because gluteus maximus activity diminishes as the leg height increases. Skilled dancers, however, do not make these torso and pelvic accommodations to such a degree that the torso appears to collapse and shorten. In other words, these compensations must be kept to a minimum for aesthetic reasons. The participants hyperextended the knee at the height of the battement, giving the illusion that the whole leg went higher. The EMG data was highly variable, despite homogeneous training in the participants. The researchers suggest that due to this variability, it is ineffective to dwell on specific muscle activation, but rather teachers should use imagery and focus on whole body actions to encourage the desired movement. There is further theoretical discussion of how the results compare to grand battement when executed at the barre. The researchers observed marked weight shift in the sagittal plane in their participants, which they suggest is not executed when using the barre. They suggest that care must be taken so that an overdependence on the barre does not develop, at the expense of a responsive use of the torso.

In Ranney's chapter in *The Science of Dance Training* (1988), he describes an article by Ryman and Ranney titled "A preliminary investigation of skeletal and muscular action in the grand battement devant", published in Dance Research Journal. However, no article by this title exists in the literature, and therefore it has been concluded that this discussion is referring to the same article described above. Interestingly, Ranney gives some additional information not in the published article. He makes reference to eight additional participants from another dance school. Results are consistent with the above conclusions, that is, the gluteus maximus must decrease activity despite teachers' encouragement to maintain a high level of contraction in this muscle, the gesture leg loses external rotation at the height of the battement, and the pelvis rotates 30º into posterior pelvic tilt. He supports previous recommendations that teachers reconsider how they are teaching this task.

Bosco Calvo, Iacopini, and Pellico (2004) examined the grand battement devant and à la seconde in three conditions: eyes open, eyes closed, and with imagery. Data were collected with a six-camera Peak Motus video system. Participants were professional dancers and full-time dance students with ballet or contemporary backgrounds. Number of participants and method of analysis were not stated in this abstract. Results indicated that there was significant posterior pelvic tilt in the grand battement devant, and significant lateral pelvic motion in grand battement à la seconde, supporting previous research on these dance movements.

Wang, Huang, Hsieh, Hu, and Lu (2008) examined the grand battement in Chinese dance. This paper is a brief translation of an article in Chinese, and information is limited. Data were collected using cinematography, EMG electrodes on the erector spinae, gluteus maximus and biceps femoris, and a goniometer was used to measure hip and trunk flexibility. Participants were 22 female dancers who performed eight trials of the selected movement. Means and standard deviations were calculated, but no other information was given regarding analysis. Results indicated that there were differences between the preferred and non-preferred leg, but unfortunately due to translation issues, no other results can be reported.

2.2.9 Forward stepping.

Krasnow, Chatfield, and Blessing (2002) compared three elite and three novice dancers executing a shift of weight in space from a one-legged balance on the right leg, followed by a forward step, resolving on a one-legged balance on the left leg. This study was described in a conference abstract. Data were collected using EMG electrodes placed bilaterally on the abdomen and erector spinae, a four-camera Peak Performance motion analysis system with markers placed along the plumb line of the body, and two forceplates, under the initial stance leg and the resultant balancing leg. Participants were tested on two separate days to test for day-to-day variability. Analysis was descriptive based on visual examination, looking at EMG ensemble graphs of each participant's trials, consisting of 15 trials per participant per day. Results indicated that elite dancers' alignment was less variable than the beginners' alignment, and further, the elite dancers' verticality improved after the shift of weight, while the beginners' verticality deteriorated. There were differences between the EMG data of the two groups; the elite dancers had a clear abdominal muscle activation pattern - right abdominals were active in the initial balance, a bilateral burst occurred during the weight shift, and left abdominal activity was found in the final balance – while the beginners' use of abdominals was erratic. These differences may indicate a training effect.

Ojofeitimi, Bronner, Spriggs, and Brownstein (2003) investigated elite and untrained dancers executing pedestrian movement requiring weight shift, resolving in a one-legged balance. This study is described in an abstract and complete details are not available. Data were collected with a five-camera motion analysis system and a forceplate. Participants were 17 elite dancers and 17 non-dancers (20 female, 14 male). Independent t-tests were performed to assess differences between the two groups. Although there were no significant differences in reaction time or joint movement sequences, the elite dancers maintained verticality and had better control of the gesture limb during the balance.

Chatfield, Krasnow, Herman, and Blessing (2007) did follow-up analysis and discussion on the study discussed previously (Krasnow, Chatfield, and Blessing, 2002). Examination of the ensemble graphs indicated that elite dancers and beginners both demonstrated a similar wave pattern for anterior / posterior sway of the torso during the forward step. Prior to stepping, participants performed a plié on the supporting leg, and during this phase there was anterior sway. During the shift of weight, the torso sway was posterior. While both groups demonstrated this pattern, the anterior sway for the elite dancers was twice as large as their posterior sway, but the opposite was the case for the beginners. At resolution, the elite dancers were close to vertical, whereas the beginners were considerably posterior to the vertical line. The surprising result was that the overall amount of sway was the same for both groups, suggesting that elite performance is not more "rigid" with less dynamic accommodation than beginners during shift of weight. EMG analysis focused on bursts of activity, not amplitudes, and therefore no MVCs or MVICs (maximum voluntary isometric contractions) were collected. While both elite and novice dancers showed consistent abdominal and erector spinae activity, there were different patterns observed. Elite dancers had unified single bursts of abdominal activity, whereas beginners had double burst patterns. Overall the elites demonstrated abdominal patterns that were more synchronized bilaterally, and better timed for control during the resolution balance phase. Finally, looking at individual data, there is much greater variability between novice dancers, than between elite dancers. The kinematic data of the three beginners was so variable that the ensemble data did not resemble two of the three individual graphs, suggesting that it may be necessary to look at individual rather than group data to gain a full understanding of dance movement strategies.

2.2.10 Turns.

Laws and colleagues have conducted several studies examining turns in dance (Laws, 1978-9; Laws, 1986; Laws & Fulkerson, 1992/93; Sugano & Laws, 2002). The early studies share certain research parameters: single-subject design, photography or videography to collect data, and physics formulas for analysis. Laws (1978-9) measured torque and resulting angular momentum of a dancer initiating a turn. In addition to photography, a platform and oscilloscope were used for data collection. The participant, a female professional ballet dancer, executed a series of three types of turns: pirouette en de hors, arabesque turn, and pirouette an dedans with the gesture leg in low second position. Fifty trials were completed over two days. Laws described the turns qualitatively, and made suggestions about how to do these turns with correct technique and efficiency. Laws (1986) examined the mechanics of the fouetté turn, collecting data with videography from the front and from directly overhead. The participant, one advanced ballet student, performed a supported turn sometimes called a finger turn, because the partner supports the dancer using one finger placed overhead. Laws constructed a geometric model of the turn, and described a correlation between three different techniques in determining the length of the pause during consecutive turns. Laws and Fulkerson (1992/93) investigated the pirouette, collecting data on video with one professional ballet dancer. They used formulas for measuring results and concluded that the number of turns is dependent on the initial momentum, and that balance limits the number of turns possible.

Sugano and Laws (2002) investigated the pirouette, integrating principles of physics and pedagogy in their analysis. For data collection they use a 3 X 4 foot platform and a bathroom scale to measure the weight on front foot prior to the turn. Participants were 25 collegiate dance students of varying levels of training, who performed controlled multiple turns. A total of 190 turns were executed. The researchers measured the width of the fourth position preparation, comparing successful and non-successful attempts. They charted the results and found the following: (1) the pirouettes improved when the width of fourth position preparation was increased; and (2) the initial proportion of weight on each foot must be controlled, which was best for the intermediate dancers.

2.2.11 Elevation work.

Of all the dance movements investigated with biomechanics tools, elevation steps are by far the most researched. Numerous studies investigate and analyse vertical jumps, leaps, turning elevation steps, and multiple variations. Also included in this section of the review are studies examining impact forces in tap and Flamenco dance. Although the steps executed in these studies would not technically be considered jumps in a dance genre such as classical ballet, the researchers were investigating similar impact and loading forces of striking the floor and effects on the joints of the body.

2.2.11.1 1970s: Early work profiling technique.

Buckman (1974) investigated the technique of performing the tour jeté during the takeoff phase, jump and accompanying rotation phase, and the landing phase. Data were collected using a 16mm movie camera (side view), a clock to time the various phases, a yardstick near the dancer, and a frame-by-frame microfilm reader. Participants were three professional dancers, three semi-skilled university dance majors, and three beginners. The three professional dancers performed four tour jetés, and the other six dancers performed three tour jetés. Analysis consisted of tracings made on selected frames, and drawings made from these tracings. Each group’s tracings were super-imposed to create one image; Buchman then did descriptive analysis of the line drawings and measured angles. There were marked differences between groups. The skilled group executed the tour jeté as described by Vaganova, except for the rotary component, which began as the participant left the ground, not in air. The skilled participants minimized horizontal traveling by leaning away from the direction of travel during the takeoff phase, thus enhancing vertical elevation. The semi-skilled and novice dancers used erect and forward leans, resulting in less vertical elevation and more horizontal traveling.

Ryman (1978) analysed six elevation steps performed by one professional ballet dancer: grand jeté en avant, pas de chat jeté, temps levé en avant en arabesque, grand ballonné en avant, grand foette sauté, and grand jeté dessus en tournant, commonly called the tour jeté. Data were collected using cinematography, and analysis consisted of quantitative evaluation using traces, tables and graphs, plus qualitative description of the grand jeté dessus en tournant. Four results emerged from this study that contradict previous pedagogical theories about elevation work: (1) It is a false assumption that deeper pliés yield higher elevation; in this study, the moderate pliés yielded the best results; (2) suspension at the top of an elevation step is an illusion, that is, the ascent and descent are one continuum; (3) for turning elevation steps, the turn must begin at pushoff, not at top of elevation; and (4) the foot sickles at moment of pushoff.

2.2.11.2 1980s: Work profiling technique.

Wiley (1987-8) investigated the saut de basque, an elevation step common in the classical vocabulary. Data were collected with a camera, and tracings were made on the film every twenty frames. One male professional ballet dancer performed 15 trials. For analysis, the movement was broken down into five phases, and the balletic model was compared to a biomechanical model. Wiley describes multiple errors that can occur when executing this step, too numerous to name in this review. Examples include too much bounce in the run (approach phase), too deep or too shallow a demi-plié (preparation phase), bending the gesture leg during the swing (take-off phase), lack of simultaneous extension of both arms and both legs (flight phase), and overall misalignment (landing phase). Wiley concludes by stating that it is essential to use scientific analysis to improve dance pedagogy.

Dozzi (1989) compared the biomechanics of dancers' jump landings with varying pedagogical directions. Data were collected using a force platform with a heel switch to determine heel contact, and an accelerometer on the tibia just below the knee. Participants were 10 advanced ballet students. They performed five continuous jumps in first position turned out, cued to aim for maximum height in three conditions: their 'normal' jump landing technique (NOR), forced heel contact or what is called pressing the heels into the floor on each landing (FHC), and intentionally allowing no heel contact (FNHC); order of the three sequences was randomized. For analysis, the first, last and any jumps not meeting the criteria for the condition were discarded. Two jumps in each condition were analysed by determining the means and standard deviations of elevation, and other joint factors. Results indicated the following: (1) For the NOR condition, only 1 in 20 jumps did not have heel contact; (2) in forced heel contact, there were more heel double-strikes, considered to increase the potential for injury; (3) mean peak forces were greatest in the FHC condition; (4) elevation was no different in the three conditions; and (5) there was greater shock absorbency in the NOR and NFHC conditions than in the FHC condition, suggesting to the researchers that the teaching cue of pressing the heels to the floor in jump landings is not a good teaching tool, but rather the light heel contact these advanced dancers demonstrated in their normal technique is a better strategy.

As with the turn studies, Laws and colleagues have investigated various elevation steps using physics principles and analysis (Laws & Lee, 1989; Laws & Petrie, 1999). Laws and Lee (1989) analysed the grand jeté using videography. The participant was one professional dancer, who performed 10 trials. Analysis consisted of physics formulas to calculate aspects of the grand jeté such as velocity and momentum. Results included the following: (1) the time that the head and torso move horizontally at the top of the jeté can be more than half of the flight time; (2) the jeté is less effective if turnout of the push-off foot is maintained during the take-off phase; and (3) about half of the energy of the total jeté is expended in the take-off. The main focus of this article was to demonstrate how knowledge of physics principles can assist the dancers in improving execution of the grand jeté.

2.2.11.3 1990s: Examining additional elements - Momentum, forces, motor strategies, interventions

McNitt-Gray, Koff, and Hall (1992) compared dancers of varying levels performing two types of jumps, examining foot position and its effects on landing mechanics. Data were collected using a one-camera Peak Performance motion analysis system and a forceplate. Participants were six professional modern dancers, six college dance students, and six non-dancers, and they performed three trials of each of two conditions: two-foot landings in first position parallel and first position turned out. Trial order was randomized. The participant’s preferred trial in each condition was selected for analysis using ANOVA. Dancers and dance students used significantly greater hip and knee flexion than non-dancers. Regardless of level, all participants used similar ankle dorsiflexion, but the professional dancers and dance students used a greater range of dorsiflexion throughout the movement, suggesting that plantar flexion was significantly greater for these two groups than the non-dancers. Despite differences in kinematics, there were no significant differences in impact peak magnitudes or foot position in landings. There were also no significant differences in landing mechanics between parallel and turned out positions.

Rasmussen and Hay (1993) were also interested in examining the extent to which the dancer “hangs” or “suspends” in the air during elevation work. Data were collected using a one-camera Peak Performance motion analysis system and markers placed on 21 body landmarks. The participant was one female advanced ballet student who performed four types of leaps: grand jeté, jeté développé, sissonne fermée, and a split leap. A series of trials were recorded, and the best trial for each condition was used for analysis, done by calculating time spent in the air for various body segments. “Hang time” was defined as the time that the centre of gravity for the whole body follows a parabolic path but the centre of gravity for the head, neck and trunk stays on a plateau. Results indicated that the “hang time” of the four jumps varied; it was longest for the jeté développé, followed by the grand jeté. “Hang time” for the sissonne fermée was only slightly less. The split leap had poor “hang time”, which the researchers suggest was due to her poor timing of raising and lowering the legs. In general, in this study the contribution of the arms to jump height was negligible compared to the contribution of the trunk and legs. Finally, the researchers state that traditional ballet technique conflicts with optimal strategies for achieving the illusion of suspension in elevation work.

Simpson, Jameson, and Odum (1996) wanted to determine how jump distance correlates to patellofemoral pressures. Data were collected using a Lo Cam camera with right-side view, markers on the right side of the body, and forceplates. Instead of using EMG electrodes to calculate muscle use, the researchers used a specialized system to determine muscle force called an inverse dynamics model. Participants were six female modern dancers with a minimum of one year of training, selected by their instructor for jumping ability. Participants first performed 10 jumps in each of three conditions: 30%, 60%, 90% of the participant's maximum jump distance, followed by 10 trials in a range of jump distances, maintaining balance at the end of the landing, used for analysis. Analysis consisted of ANOVA and Scheffé post hoc analysis, plus equations for determining linear velocities and accelerations. Results showed that as the distance increased, peak patellar pressures increased, knee flexion increased, and time to these events decreased, that is, velocity increased.

Simpson and Kanter (1997) reported on Part 1 of a study examining the effect of jump distance on ankle and knee joint axial forces. Data collection was similar to the previous study. Six skilled female modern dancers performed 10 trials in each of three conditions: 30%, 60%, 90% of the participant's maximum jump distance, followed by 15 trials in a range of jump distances, maintaining balance at the end of the landing, used for analysis. Multiple calculations and formulas were computed to estimate several parameters, and then qualitative assessments were performed. Several outcomes were observed, including the following: (1) Increased jump distance was correlated to greater ground reaction force maxima, greater knee flexion, greater knee and ankle flexion velocity, and greater tibial landing angle. (2) Muscle axial forces have a greater impact than other forces on the magnitude and rate of applying compressive forces at the knee and ankle joints. These high rates of axial forces during large jump distances could be responsible for excessive wear on the joints of the lower extremities. Simpson and Pettit (1997) reported on Part 2 of the same study. Results indicate the following:

(1) Increased jump distance was correlated to greater knee and ankle joint reaction shear forces and greater quadriceps shear forces. (2) Increases in ankle joint shear forces occurred in all participants with increased jump distance. (3) Increased quadriceps shear forces at greater jump distances correlated to increased knee shear forces for only half of the participants.

Laws and Petrie (1999) investigated the use of momentum transfer, particularly from the arms, in enhancing vertical jumps in dance. For data collection, the participants jumped from a 2-inch X 12-inch X 6-foot board rigid at one end and supported on the other end by a force sensor. Participants were seven trained ballet dancers (six female and one male) and one female athlete with no dance experience. They performed a series of jumps in two conditions: one with the arms held at the sides, one with the arms raised during the push-off phase. Force-time plots were graphed, and jump height was calculated using formulas. Results indicated the following: average height gain using the arms was 26%; older, mature dancers increased magnitude of the push-off phase to increase jump height, while smaller, younger dancers increased the duration of the push-off phase; extended duration of push-off phases contributed more to jump height than increased magnitude; less coordination in the use of the arms resulted in less height increase.

2.2.11.4 2000s: Recent work - Laterality, gender, body composition.

Harley, Gibson, Harley, Lambert, Vaughan, and Noakes (2002) compared dancers and physically active non-dancers to assess quadriceps strength in relation to EMG activity during isometric and stretch-shortening cycle (SSC) muscle activity. Other physiological characteristics (e.g., body composition and flexibility) were also assessed. Data were collected with EMG electrodes placed on the right rectus femoris, a Kin-Com dynamometer, and a forceplate. Participants were 11 female semi-professional dancers and 11 matched participants who were participants in various forms of physical activity, but had no dance training. MVICs were collected in order to compare the two groups use of relative percentages of maximum. Participants performed a variety of tests including maximum knee extensor isometric muscle strength, three types of jumps to determine the SSC (squat jump, counter-movement jump, and drop jump), and the vertical jump. Analysis included t-tests and Pearson Product-Moment correlation. Results included the following: Dancers generated greater quadriceps muscle output than non-dancers during jumping trials, but they did not jump significantly higher. When jumping, they used a lower percentage of their rectus femoris MVIC as measured by EMG, than the non-dancers. The researchers hypothesize three possible reasons for this outcome: (1) dancers may be sacrificing height for aesthetics, (2) there may be training-induced differences in neuromuscular patterns in the dancers, or (3) there may be differences in the elastic components of the musculo-tendinous tissue between the two groups. The researchers make suggestions for teachers to find ways to address this issue of not using full strength potential to achieve higher jumps in dancers.

Martin, Kulas, and Schmitz (2005) analysed the asymmetry of ground reaction forces in dancers landing from a drop jump. Data were collected using two forceplates. Twenty college female dancers performed drop jumps at a height of 60cm in three landing conditions: preferred, soft, and stiff techniques. The participants always began with their preferred landing, and led off the box with the right leg. Number of trials was not specified in this abstract. Analysis consisted of repeated measures ANOVA. Results indicated that mean maximum vertical ground reaction force was significantly higher for the right leg for each condition. Mean time to peak vertical ground reaction force was significantly less for the right leg for each condition. The researchers suggest that any research examining jumps and ground reaction force need to use two forceplates, as the forces experienced by the two legs may be different.

Mayers, Agraharasamakulam, Ojofeitimi, and Bronner (2005) investigated musculo-skeletal stresses experienced in tap dance. Data were collected with a five-camera Vicon motion analysis system with 39 reflective markers, and a forceplate. Six professional tap dancers executed four tap sequences: flaps, cramprolls, pullbacks, and the participant's choice. Each step was repeated 4-8 times. Analysis consisted of t-tests. Because there were no gender differences, results for all participants were merged for analysis. Landing forces in the vertical plane were lower for tap dance than results reported for other dance forms, which may account for the lower incidence of injury in professional tap dancers than other forms. The researchers suggest that it would be useful to analyse individual joint forces in tap dancers.

Orishimo, Kremenic, Pappas, Hagins, and Liederbach (2009) compared drop landing biomechanics in male and female dancers. Data were collected with an 8-camera Eagle motion analysis system, using 20 reflective markers, and a forceplate. Participants were 33 professional ballet and modern dancers, 12 men and 21 women. Participants performed three single-leg drop landings from 30 cm platform, landing on the dominant leg on the forceplate. For analysis the mean values of all three trials were calculated, and two separate multivariate ANOVA (kinetics and kinematics) were performed, followed by t-tests. Results demonstrated no gender differences with both males and females using good lower extremity alignment in the landing and a hip dominant strategy. There was a significant difference between the age at which the dancers began training and the peak hip adduction angle during landing. The researchers suggest that previous research showing gender differences may have been using less experienced dancers.

2.2.12 Motor Strategies.

In a theoretical article, Laws (1985) discusses the use of the barre in dance training. This is not a research study, and has no participants and no experimental protocol, but the topic is relevant to this review, due to the number of research studies examining this issue. Some of Laws’ observations include the following: (1) at the barre, more forward shift of torso is possible in performing arabesque than may be possible in centre work; (2) the barre allows for stabilization of the torso in movements such as rond de jambe, which may require internal stabilization techniques in centre; (3) turn initiations using the barre cannot be executed in centre work in the same manner; (4) in summary, the barre has important uses but some of the ways it is currently used may not be transferable to work without a barre.

Chatfield (1993/94) examined EMG activity in dancers, comparing isokinetic work to dance movements. Data were collected with EMG electrodes placed on the rectus femoris, biceps femoris, tibialis anterior and lateral gastrocnemius. A Cybex dynamometer was used for muscle testing. Participants were seven collegiate advanced dancers. With the Cybex, the muscles were tested at various speeds and positions most commonly reported in the dance literature. The dance movements tested were four sequences: a plié / relevé sequence, a développé sequence front, side and back, a grand battement sequence front, side and back, and a jumping sequence. Continuous strip chart recordings were produced from the data, and relative values were used to compute group means. Results demonstrated that dancers showed higher levels of muscle activity in dance movements than in the isokinetic testing with the Cybex. Chatfield suggests possible reasons for this outcome, and states that isokinetic testing may be limited in its uses for dance research, particularly when investigating simultaneous muscle function at multiple joints, and stabilization functions of muscles in complex movement. Finally he suggests that research include kinetic and kinematic measures, in addition to EMG data collection, to provide a full view of the complexity of the neuromuscular demands in dance.

Chatfield, Barr, Sveistrup, and Woollacott (1996) conducted two studies designed to examine movement repatterning in dance. In study 1, data were collected with EMG electrodes placed on the pectoralis major, rectus femoris, and rectus abdominus. Participants were three collegiate dancers who executed a simple whole body movement, an abdominal contraction resulting in spine flexion with accompanying limb movements, in two conditions, supine and standing on a one-legged balance. Participants did three trials in each condition, received coaching by a certified movement analyst, and then repeated the trials. Analysis consisted of within-subjects 3 X 3 X 4 (subjects by trials by conditions) ANOVA. There was a significant interaction between subjects and conditions, though the researchers state that this interaction may have masked training effects. The researchers concluded that it was necessary to examine outcomes for individuals, not groups, to understand the data, and a descriptive discussion of each participant’s results followed. There were different results for the standing versus supine condition, suggesting that the issue of transfer of training from one context to another needs further investigation. In study 2, dancers were compared with non-dancers in a similar movement task. Data were collected with EMG electrodes placed on the midpoint between umbilicus and pubis symphysis, and kinematic data were collected with a two-camera Watsmart motion analysis system, with markers on the wrist and ankle. Participants were four female advanced collegiate dancers and five female non-dancers. All participants received four 90-minute training sessions with a certified movement analyst over a two-week period. Analysis was a mixed within-subjects 2 X 5 (groups by trials) ANOVA. There was a significant difference between group means. Results included the following: (1) the dancers were highly consistent in the centrally initiated movement used in this study, and (2) the dancers were better than the non-dancers at achieving the task, even though the non-dancers received training.

Laws (1998) wrote a theoretical article discussing the transfer of linear and rotational momentum in dance movements, such as vertical jumps, pirouettes, fouetté turns, finger turns, and whip turns. Each jump or turn is described and analysed using physics principles and formulas. Some of the observations included are the following: the use of arms can increase vertical jump height by 25%; the rate of turn for the pirouette is maximized if the arms are kept close to the body and a “windup” preparation is allowed; for the fouetté turn, the gesture leg should reach maximum abduction and external rotation to produce the best momentum for the turn. Although the majority of this article is biomechanical analysis, there is one pilot study described. A system was constructed to simulate a partner in a finger turn, with a force sensor substituting for the partner's hand. One dancer executed the turn with four different accelerating techniques. The study indicated that the technique which resulted in the maximum turning momentum was consistent with what is considered to be "correct" technique, that is, the leg extended to croissé devant, then moved fully to the side, and then moved to the pirouette position. Laws concludes that the appropriate use of momentum can yield the most efficient technique if principles of physics are understood and applied.

Chatfield (2003) discusses the use of EMG and kinematic tools, and how variability in data can be handled and analysed. This article does not describe a particular research study, but rather serves as a theoretical work, lending insight into ways of viewing and dealing with data variability. Chatfield describes variability in two instances: (1) within a single participant's repeated execution of the same task, and (2) differences seen between participants. After reviewing several studies in the dance literature, he discusses how variability can be seen as an indicator of motor learning, and can provide valuable information to the researcher and educator, by tracking training changes over time, or by differentiating between experts and beginners.

Liederbach, Dilgen, Daugherty, Richardson, and Rosen (2003) compared end-range strength in knee flexion of normal knees versus knees with anterior cruciate ligament reconstruction, either with semitendinosus/gracilis grafts or patellar tendon grafts. In this conference abstract, there is minimal information provided. Data were collected with motion analysis and strength testing equipment.

Participants were 60 female and 60 male dancers. Tests included a single leg stance, dual and single leg jump landing, and manual muscle testing of end-range, eccentric hamstring strength. Participants with semitendinosus/gracilis grafts and with patellar tendon grafts were compared to participants in the normal (no ACL reconstruction) group. Additionally, participants' knees with ACL reconstruction were compared to the ipsilateral normal knee. Unfortunately, at the time this abstract was submitted, no results were reported, and to date, the study has not been presented in the literature.

2.3 Summary of Literature Review

2.3.1 Overview.

The overwhelming number of studies devoted to elevation work is worthy of mention. This fascination with elevation work crosses all four decades, and has been examined across genre, age groups, and technical levels. What drives this intense interest in one aspect of dance vocabulary? It may be due to the high impact forces involved, and the potential for career ending injuries. Possibly it is related to the distinct beginning and end to elevation movements, allowing for clarity in data collection. Or it may reflect the extensive number of descriptions in the pedagogy literature for correct execution of these steps, and a desire to test these theoretical models. Another question that can be posed in this context is the following: Research suggests that grand plié is not simply a deepening of the demi plié in terms of muscle activation, and that the rise to full pointe is not simply a continuation of the relevé. This raises the issue of the relationship of plié and relevé to jumping mechanisms. Motor control theory tells us that plié/relevé and jumping are different motor strategies, but no research to date has examined the difference in these two movement conditions in terms of muscle activation. No one has yet investigated whether dancers use the same muscles in both activities to differing degrees and speeds, or if there are different organizations of muscles employed to leave the ground.

2.3.2 Measurement tools.

Regarding measurement tools, researchers used photography, filming, video, motion analysis systems (Elite, Peak, Watsmart, Expert Vision, Ariel, Vicon, Hires, Spica, Eagle), EMG collections, forceplates, and some used other data collection apparatus. Some of the articles were entirely theoretical, and did not use any measurement tools.

There is a clear shift in the literature from the use of cinematography to the use of motion analysis technology. The early studies in the 1970s and 1980s use photography and motion picture film cameras, and tracing techniques, to collect and analyse data. Standing out as an exception to this pattern is the work by Woodruff (1984) who used motion analysis equipment in her examination of the plié. Motion analysis does not reappear in the literature for eight years, in the 1992 study by Mouchnino, et al. Perhaps this speaks to the limited access dance researchers had in the early years of dance science exploration to the technology that existed and was already in use in biomechanics labs and science-based departments. By the mid 1990s and later, use of motion analysis is in much broader use, and the benefits to the dance field are immeasurable. Kinematics has provided educators and clinicians with insights into the movement strategies of dancers, and differences between novice and elite dancers, that previously would have been unavailable. There are, however, certain key themes that recur regardless of the tools, and these will be discussed in the next section of the discussion.

The use of electromyography in dance analysis is both complex and confusing. In the articles examined in this review, less than half of these used some system of determining maximum voluntary contractions (MVCs) or maximum voluntary isometric contractions (MVICs) for the participants (Ferland et al., 1983; Harley et al., 2002; Lepelley et al., 2006; Ryman et al., 1978/9; Simpson et al., 1996; Simpson et al., 1997; Trepman et al., 1994; Trepman et al., 1998; Wilmerding et al., 2001), whereas in the sports research, establishing MVCs or MVICs is the norm. Without a method of determining maximums, the researcher can describe onsets of muscle activation under investigation and compare timing across individual trials or groups of participants, but not amplitudes. For certain researchers, given their research questions, this strategy is sufficient. For other research designs, it would have provided additional insight to have had the potential to examine muscle amplitudes, and describe how various groups of dancers might differ in muscle use for a given dance task. Most likely what inhibits dance researchers from taking this step is the difficulty of collecting maximum voluntary contraction data, and the lack of consensus surrounding this topic. Questions arise as to the benefits of using maximum voluntary contractions (MVCs) or maximum voluntary isometric contractions (MVICs) for data collection, that is, whether the collections should be done in isotonic or isometric conditions. It is not yet clear if these tests give a clear picture of dancers. Some dance researchers have no access to complex isokinetic equipment such as Cybex and Biodex, even if they wanted to collect this data. It would be useful to know if there are systems that do not include large, cumbersome apparatus that dance researchers can use, or if there are other methods such as percentage of dynamic maximum (Lepelley et al., 2006) or inverse dynamics model (Simpson et al., 1996; Simpson et al., 1997) that have been tested for reliability that dancer researchers can use. It is not only dance research that is struggling with design aspects of dealing with EMG data collection, and as the sophistication of the equipment improves, better research methods need to evolve for biomechanics study using EMGs in all movement fields.

It is unusual to see a dance study that uses forceplates alone as a measurement tool. Of the studies using forceplates, only two used this technology exclusively (Albers et al., 1992/3; Martin et al., 2005). It is clear that dance researchers use forceplates to augment or enhance kinematic and EMG studies, and as such this data provides valuable additional information. There may be ways that dance researchers can expand their use of forceplate data in describing dance movement, and in furthering the knowledge of ground reaction forces, in particular, and how these might correlate to dance injuries.

2.2.3 Themes.

There are recurring themes in the articles described that are noteworthy. First, it should come as no surprise that in almost every study included in this review, elite dancers demonstrate different motor strategies than novices or non-dancers, and that these differences are judged as superior. Elite dancers' muscle use is efficient, their coordination is smooth and aesthetically pleasing, their balancing strategies are effective, and overall they have higher skill sets. In the occasional study in which the elite dancers do not surpass the non-dancers, the researchers usually state that the dancers are sacrificing one movement aspect (e.g., jump height) for enhanced aesthetics. The intervention studies are not as universally consistent however, and it is not clear why many of these studies fail to yield positive or significant results. Perhaps the subject sizes are too small, or the time periods of the interventions too short to show differences, particularly with elite participants who tend to make small changes in any context. Or it may be that the interventions are simply poorly designed.

A second repeating theme is the conclusion that dancers perform differently when using a barre as opposed to executing the same movement without a barre, both in terms of muscle activation patterns and weight shift strategies. This research goes as far back as the late 1970s, and continues up to recent articles. However, the researchers raise several questions that are yet to be answered. Some claim that there may be ways to use the barre that eliminate this difference. Others wonder if there is a point of negative transfer of training, that is, if it can be determined how much time at the barre is too much time. This also raises the issue of the implications for additional transfer of training issues; for example, there may be similar differences in strategies when dancers begin moving through space. Few studies have tried to record EMG and kinematic data on dancers moving through space in traveling material, but this may be the next obvious area of exploration.

Another recurring theme is the individual variability of participants within a certain pool. It has been observed that individual dancers are more consistent across multiple trials of the same task than novices or non-dancers. Furthermore, when grouped, elite dancers demonstrate more consistent data than groups of novices or non-dancers in many of the studies reviewed. Nevertheless, there is considerable variability among participants, even when matched in terms of background, years of training, body type, and other variables. Each individual has a unique way of moving, and selecting motor strategies.

Finally, many studies in this review compare current dance pedagogy to efficient movement biomechanics. In several of the studies looking at biomechanics, it is not uncommon for the researchers to conclude that dance teachers recommend methods of achieving movement skills that are inconsistent with optimal biomechanical function. For example, Buckman (1974) compared the Vaganova literature's description of turning elevation steps to elite dancers and found that biomechanically it is essential for the rotary component of a turning elevation step to begin at the moment of take-off. However, the Vaganova literature instructs teachers to cue dancers to elevate first, and then add the rotation at the top of the jump. Laws and Lee (1989) state that a jeté is less effective and has less height if the turnout of the push-off foot is maintained during the take-off phase; they assert, however, that teachers consistently instruct dancers to maintain their full turnout in both legs during all phases of the jeté. In another analysis, Laws (1998) suggests that the rate of turn for the pirouette is maximized if the arms are kept close to the body and a "windup" preparation is allowed, and yet he states that few teachers allow a "wind-up" preparation for classical turns. He suggests that perhaps sacrifices are made with regard to optimal biomechanics to satisfy aesthetic demands, but it would certainly be of value to questions some of these inconsistencies.

Additionally, there are contradictions between what dance pedagogy recommends and the movement strategies employed by elite dancers. Ryman (1978) and

Dozzi (1989) both found several aspects of jumping techniques in elite dancers that they state contradict common teaching instructions for these dance movements. Examples include using the deepest possible plié to attain higher jumps when moderate pliés yield the highest elevation, and pressing the heels into the floor on landings as the best technical strategy, which actually encourages the double-heel strike. Similarly, studies of leg gestures involving large range of motion (Bosco Calvo, Iacopini, & Pellico, 2004; Kwon, Wilson, & Ryu, 2007; Ranney, 1988; Ryman, & Ranney 1978/79; Wilson, Lim, & Kwon, 2004) report significant pelvic tilt in elite dancers, and yet the pedagogy literature recommends that teachers should instruct dancers to keep the pelvis still in many of these gestures, including grand battement devant and à la seconde (Kassing & Jay, 1998; Lawson, 1984; Minden, 2005; Vaganova, 1969). Perhaps this cue is an effective "image" to reduce unnecessary compensations. Possibly, the elite dancers are executing the movement incorrectly, or at least lacking optimal efficiency. Or perhaps it is simply ineffective pedagogy, and teachers might improve pedagogical strategies by examining traditional practice.

2.3.4 Research Design.

In the articles in this review, nearly half had fewer than 10 participants. There is an increasing interest in single-subject design and within-subject design, in which multiple trials are collected for a single participant, or for a few participants. The argument in favor of this approach is based on the earlier observation that there is high variability among individual participants, and collapsing data into groups may mask information that is crucial to a full understanding of the movement being studied. However, the literature on single-subject design suggests that this method of research is appropriate for determining variability when using intervention protocols, where there are repeated data collections of a participant first as baseline, and then periodically to measure the effect of the intervention (Barlow, Nock, & Hersen, 2008). “Snapshot” single-subject studies in which data are collected one time to assess a participant’s motor strategies are of questionable value. If in fact there is such high variability between individual dancers, what can be learned from a study of this design? Generalizing results to a larger pool would be at best hypothetical, but might serve as a pilot study for a projected larger study. Perhaps what might produce the best of both designs is to collect data on larger numbers, examine and describe individual data thoroughly, and then proceed to collapse individual data sets into group data for analysis.

Several research ideas are suggested by this review of the literature. First, it would be valuable to examine dance movement using a variety of measurement tools. Employing kinematics, kinetics, and electromyography in a single study could potentially provide a fuller understanding of the movement being tested. Second, the issue of differences between movement executed at the barre and movement executed in the centre needs to be explored more fully. The additional component, movement traveling through space, has yet to be examined in a controlled study and compared to the barre and centre conditions. Third, if EMG data is to be used to compare muscle amplitudes across participants, a method of normalization of the data should be developed and tested that is specific to the dance population. Finally, there is insufficient information to date about differences between elite and novice dancers, and even less data about intermediate dancers. A participant pool would need to be large enough to divide into three distinct groups and still yield statistical power.

The current study was designed to address the above research questions. The movement selected for study was the grand battement devant, as there are sufficient previous studies on this movement to offer background, and because this movement easily translates from barre to centre to traveling conditions.

CHAPTER THREE

DYNAMOMETER STUDY

[portions of this chapter have been published in *Medical Problems of Performing Artists]*

Krasnow, D., Ambegaonkar, J. P., Stecyk, S., Wilmerding, M. V., Wyon, M., & Koutedakis, Y. (2011). Development of a portable anchored dynamometer for collection of maximal voluntary isometric contractions in biomechanics research on dancers. *Medical Problems of Performing Artists, 26*(4), pp. 185-194.

The concept of developing a dance specific dynamometer was developed through my extensive review of the dance medicine and science literature involving sEMG data collection, and the apparent lack of a suitable normalization procedure for dance. Due to the use of the biomechanics facility at CSUN, it was necessary for my on-site supervisor and CSUN tenured faculty member Dr. Shane Stecyk to place his name first on the Human Ethics approval forms, and on the consent forms, but his actual role was supervisory. While Dr. Stecyk assisted me in physically building the equipment, I was responsible for the dynamometer design relative to dance movement, and for the testing process. Dr. Ambegaonkar assisted me in understanding the EMG output, and the process of filtering the data, and Dr. Wilmerding consulted on the dance-specificity of the testing procedures.

In a recent review of literature, Krasnow, Wilmerding, Stecyk, Wyon, and Koutedakis (2011) noted that in the 21 dance research studies using surface electromyography (sEMG) that they considered, less than half utilized any method of data normalization in order to enable sEMG amplitude comparisons across participants or over time. The studies that did not collect data for normalization only assessed onset times of muscle activation in a given single testing session, and therefore did not require normalization procedures. The studies that collected normalization data used a variety of methods including average rectified values, manual resistance testing, and use of isokinetic equipment. To date, no dance research studies have used hand-held dynamometers or dynamometer anchoring systems.

While many research questions do not require the assessment of amplitudes, it was imperative for the purposes of this study to consider a method for the collection of sEMG normalization data to provide clearer insight into muscle activation patterns in dancers, a specialized subset of the physically active population. Therefore, the development of the PAD was in two stages: (1) The purpose of the first stage was the examination of the existing exercise science literature using dynamometer sEMG collection procedures, to determine the potential for this procedure for dance research. (2) The purposes of the second stage were the development of a portable anchored dynamometer (PAD) that can be easily constructed and implemented for dance-specific electromyographic research, and the validation of this system based on previous methodology in exercise science research and pilot studies with dancers.

3.1 Stage 1 - Review of Literature

3.1.1 Introduction

One preferred normalization procedure in sports and exercise science literature is the data collection of maximum voluntary contractions (MVCs) or maximum voluntary isometric contractions (MVICs), using a percentage of maximum values to compare participants (Ambegaonkar, Shultz, Perrin, Schmitz, Ackerman, & Schulz, 2011; Bolgla, Malone, Umberger, & Uhl, 2010; Bolga & Uhl, 2007; Kulas, Schmitz, Shultz, Henning, & Perrin, 2006; Worrell, Crisp, & LaRosa, 1998). The purpose of MVC and MVIC collections in sports analysis is to normalise sEMG data for between-subject comparisons of muscle amplitude, and for multi-session or multi-day testing for a single subject. Without normalisation of data, these comparisons could not occur, due to the nature of the data collected in sEMG research. The data do not represent muscle force generation, but rather the electrical activation level of the muscle, and normalisation allows comparisons to be made in these instances.

Regarding deep muscle contributions, it is a limitation of sEMG that deep muscles cannot be measured, only superficial muscle groups. Given this limitation, it is still possible to capture muscle force from the superficial muscles of interest in this grand battement research study.

Another criticism of the use of MVICs is that they measure muscle activation at a constant joint angle throughout the trial. The goal is to select a joint angle that produces maximum force production in an isometric trial, acknowledging that it may not always be possible to elicit a true maximum at a given joint angle. This study used joint angles determined by accepted guidelines from SENIAM (Surface

ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) Project standards (http://www.seniam.org/). Additionally, Bolgla and Uhl (2007) and Burden (2010) concluded that MVICs are highly reliable for normalization of sEMG data collected during movement trials.

3.1.2 Dynamometers for sEMG normalization.

Burden (2010) emphasized the importance of normalizing sEMG data if comparisons were made between different muscles and different individuals. In his review of the literature over the past twenty-five years, he assessed eight normalization methods, and concluded the following: (1) sEMG data from MVCs and from MVICs are equally reliable, and further, these values are as useful as using the dynamic maximum of the movement trial under investigation; (2) using either submaximal isometric values or using maximal isometric values at an arbitrary joint angle in mid-range are acceptable, as both have good reliability; (3) evidence does not support the need to match the specific joint angles during MVIC collection or joint ranges during MVC collection to the movement trials in order to have reliable comparison data; (4) dynamic MVCs should be used only if it can be determined that the task being used for the MVC collection can elicit maximal contractions in all of the muscles under investigation; and (5) in conclusion, sEMG data from an MIVC is the recommended method to use as a normalization reference value.

3.1.3 Standardized equipment.

The traditional method of collecting MVIC data has been the use of standardized equipment designed for muscle testing. However, there are pragmatic problems with the use of equipment such as the Biodex and Kin Com systems for MVC and

MVIC data collection in dance research. First, the available equipment does not allow for much flexibility in terms of body positioning for data collection on a given muscle. Second, if multiple electrodes are placed on the body, it can be difficult to place the participant on the equipment in various positions without disrupting some of the electrode placements. Third, for dance researchers, access to this equipment, particularly in a dance-suitable space, can prove challenging. Finally, dancers often find using this type of equipment so atypical of their normal training process that it is questionable if they are able to elicit maximal or reliable levels of muscle activation (Chatfield, 1993/94).

3.1.4 The hand-held dynamometer (HHD).

In seeking alternatives to the standardized equipment, researchers in sport and exercise science have explored the use of devices known as hand-held dynamometers or HHD (Agre, Magness, Hull, Wright, Baxter, Patterson, & Stradel, 1987; Andrews, Thomas, & Bohannon, 1996; Bohannon, 1997; Bohannon, 2009; Kelln, McKeon, Lauren, Gontkof, & Hertel, 2008; Thorborg, Petersen, Magnusson, & Hölmich, 2010; Wikholm, & Bohannon, 1991). The dynamometer measures the muscle force that a participant can elicit, while a trained tester provides resistance so that the participant can achieve high levels of muscle contraction.

In an early study by Agre, Magness, Hull, Wright, Baxter, Patterson, and Stradel (1987), the HHD was found to be reliable for upper extremity testing but not for lower extremity testing, due to the lack of stability of the tester. The variation coefficient of the methodology error (CV) was between 5.1% and 8.3% for all upper extremity muscle tests, which the authors considered acceptable reliability for clinical muscle strength testing, but the lower extremity values ranged from

11.3% to 17.8%, resulting in poor reliability.

Andrews, Thomas, and Bohannon (1996) assessed an HHD device examining eight upper extremity and five lower extremity movements, and used the results to determine normative values for populations 50-79 years old. The researchers concluded that while the testing methodology is reliable, the training, experience and strength of the tester are important factors.

Wikholm and Bohannon (1991) had three testers measure two upper and three lower extremity muscles for 27 participants. They selected three testers with measurably different strength levels, and muscles with different maximum force productions. They found that there was considerable variability in results. As the tested muscles increased in force production, the interrater Intra Class Coefficients (ICCs) decreased in magnitude (.932 to .226). Similar results were seen for intrarater/intrasession ICCs. They concluded that these results were most likely due to differences in individual examiner's strength levels and the subsequent resistance they were able to offer to the participants during testing.

Bohannon (1997) had one tester assess six upper extremity and four lower extremity muscles for 106 men and 125 women, and confirmed that reliable measurements could be obtained using an HHD. He observed, however, that the tester must be strong enough to provide sufficient resistance to the participant's efforts, and the technique must be clearly defined, systematic, and consistent.

Kelln, McKeon, Lauren, Gontkof, and Hertel (2008) tested eleven lower extremity muscles of 20 participants, using three testers on two separate days, with the following results: Intratester ICC’s ranged between .77 to .97 with standard error of measurements (SEM) range of .01 to .44 kg. Mean intertester ICC range was .65 to .87 with SEM range of .11 to 1.05 kg. Mean intersession ICC range was .62 to .92 with SEM range of .01 to .83 kg. Similar to Bohannon (1997), Kelln suggested that the limitation of such a hand-held device was in attempting to test movements in which the participant could overpower the tester.

Bohannon (2009) reviewed thirteen published articles in the literature using HHDs, to determine the responsiveness of the testing device over time. Using effect size as the measure of responsiveness, he concluded that HHD could detect changes in limb strength due to interventions. Thorborg, Petersen, Magnusson, and Hölmich (2010) used the HHD to assess hip abduction, hip adduction, hip external rotation, hip internal rotation, hip flexion, and hip extension, all of which would be highly applicable to dance research. In test-retest trials, he examined measurement variability, and found highly reliable results, with measurement variation between 3-12% for the various muscles between sessions. It should be noted that the tester did enthusiastic cueing during these data collection sessions, which was seen as an important component in getting reliable results.

3.1.5 Portable anchored dynamometers (PAD).

In order to mitigate the problem of the participant overpowering the tester, and to provide more consistent positioning of the resistance, researchers have designed portable anchoring systems, using solid apparatus and belts as the resistance modality. For example, Kramer, Vaz, and Vandervoort (1991) used a combination of HHD and belt resistance, and found that this method required less strength on the part of the examiner, greater stabilization of the participant, and was preferred by the majority of participants. Similarly, Bolgla and Uhl (2007) compared the reliability of three normalization methods for testing hip abductor strength: maximum voluntary isometric contraction (MVIC), mean dynamic activity, and peak dynamic activity, all using a table and resistance belts. The researchers concluded that this MVIC collection method provided the highest level of reliability. They further commented that factors that impacted reliability were body positioning, verbal encouragement, and task familiarization.

Nadler, DePrince, Hauesien, Malanga, Stitik, and Price (2000) designed a portable dynamometer anchoring station that measured the strength of the hip extensors and abductors. Ten participants were tested twice, two weeks apart, with the evaluators blinded. They computed the intraclass correlation coefficients for both maximum (ICC 1,1) and average (ICC 1,3) strength, which ranged from .94 to .98. Average CV (coefficients of variation) for maximal abduction strength was 4.77%, and for average abduction strength was 4%. Average CV for maximal extension strength was 8.06%, and for average extension strength was 7.83%. Thus they concluded that this method of collection was highly reliable, and particularly useful for testing powerful muscles that might not be easily assessed using an HHD device.

Finally, Scott, Bond, Sisto, and Nadler (2004) compared the inter- and intra-rater reliability of a portable anchored dynamometer (PAD) to an HHD, assessing hip abduction, extension and flexion, using two testers with a one-hour break between sessions for the participant. Interrater ICCs of average peak strength ranged from .84 to .92 (hip flexors), .69 to .88 (hip abductors), and .56 to .80 (hip extensors). Intra-rater ICCs ranged from .59 to .89 for tester A and from .72 to .89

for tester B using the PAD, and from .67 to .81 for the HHD across muscle groups. The PAD was highly reliable for hip flexion and abduction, whereas the HHD was more reliable for hip extension. They concluded that both systems yielded reliable test results.

In summarizing the literature about sEMG normalization procedures, MVICs are highly reliable for normalization of sEMG data collected during movement trials (Bolgla & Uhl, 2007; Burden, 2010). Standardized equipment is problematic for dancers (Chatfield, 1993/94), but dynamometers can reliably determine muscle strength for the purposes of muscle testing (Agre, Magness, Hull, Wright, Baxter, Patterson, & Stradel, 1987; Andrews, Thomas, & Bohannon, 1996; Kelln, McKeon, Lauren, Gontkof, & Hertel, 2008; Wikholm & Bohannon, 1991), and the limitations due to tester strength and variability can be overcome using PADs (Bolgla & Uhl, 2007; Kramer, Vaz, & Vandervoort, 1991; Nadler, DePrince, Hauesien, Malanga, Stitik, & Price, 2000). Other recommendations include familiarity with procedures and enthusiastic cueing (Thorborg, Petersen, Magnusson, & Hölmich, 2010).

Stage 2 – Need for a Dance-Specific PAD

To date, no PAD described in the literature has been devised for dance medicine and science research. The anchoring systems presented in the sports and exercise science literature do not always replicate the typical movement patterns during dance movement. For example, in sports and exercise science, the PADs typically test the gluteus maximus in the seated position with the participant pressing downward; however dancers are more familiar with use of this muscle in movements such as the arabesque, where the dancer is in a one-legged stance with the free leg behind the body in hip and knee extension. Therefore, a customized PAD was designed for this study that addressed dance-specific issues.

The second stage of the project was the development of a portable anchored dynamometer (PAD) that can be easily constructed and implemented for dance-specific electromyographic research, and the validation of this system based on previous methodology in exercise science research and pilot studies with dancers. First, a previously reported PAD was used as a model, modifying body positioning to create a similarity to dance movements. Second, procedures were replicated that are reported to result in reliable results in previous literature. Third, the PAD was tested on dancers, asking them for subjective feedback on comfort and effort levels when using this apparatus.

3.2.1 Methods.

Participants: Ten trained female dancers (mean age 31.0 ± 15 yrs, mean height 163 ± 7.6 cm, mean mass 57.6 ± 6.9 kg, and 17.0 ± 13.9 yrs of training in ballet and/or modern dance) participated in this study. Participants were only included if they had no injuries that might impede successful completion of the tasks. Dancers were intentionally selected with a broad range of demographics, due to the potential variable participant pool for future research. All test procedures were described and explained to the participants prior to preparation for testing and data collection whereupon they signed an informed consent form. All procedures were approved by the Standing Advisory Committee for the Protection of Human Subjects at California State University, Northridge.

General approach: The method first proposed by Nadler, DePrince, Hauesien, Malanga, Stitik, and Price (2000) was modified for this study. The PAD incorporates several of the positive variables described in previous research (Bolgla & Uhl, 2007; Bohannon, 2009; Thorborg, Petersen, Magnusson, & Hölmich, 2010; Kramer, Vaz, & Vandervoort, 1991; Nadler, DePrince, Hauesien, Malanga, Stitik, & Price, 2000), including a combination of a table and resistance belts for stability, body positioning that is familiar to the dancer, practice trials, and enthusiastic cueing during collections.

The instrument: The apparatus components can be seen in Figures 1-8. The system consisted of the following equipment: (1) a padded treatment table; (2) a lightly padded removable back support that was mounted on the table for the seated work and adjusted so that the participant's knees reach the end of the table in the seated position; (3) an adjustable, padded board with clamps (Irwin® Quick-Grip® Clamps) that can be attached onto the table legs and adjusted to adapt to the height and leg length of the participant; (4) straps for stabilizing the participant for the MVIC tests; and (5) a 6" diameter foam roller to assist with knee flexion in some of the electrode placements and some of the MVIC data collection.

Eight muscles were selected for testing bilaterally. These muscles were chosen for two reasons. First, they are commonly tested in EMG studies in the dance science literature (Bartolomeo, Sette, Sloten, & Albisetti, 2007; Chatfield, 1993/94; Chatfield, Barr, Sveistrup, & Woollacott, 1996; Chatfield, Krasnow, Herman, & Blessing, 2007; Clippinger-Robertson, Hutton, Miller, & Nichols,1986; Couillandre, Lewton-Brain, & Portero, 2008; Ferland, Gardener, & Lèbe-Néron, 1983; Krasnow, Chatfield, & Blessing, 2002; Lepelley, Thullier, Koral, & Lestienne, 2006; Massó, Germán, Rey, Costa, Romero, & Guitart, 2004; Monasterio, Chatfield, Jensen, & Barr, 1994; Mouchnino, Aurenty, Massion, & Pedotti, 1992; Ravn, Voigt, Simonsen, Alkjaer, Bojsen-Moller, & Klausen, 1999; Ryman & Ranney,1978-9; Trepman, Gellman, Solomon, Murthy, Micheli, & De Luca, 1994; Wang, Huang, Hsieh, Hu, & Lu, 2008; Yoshida & Kuno-Mizumura, 2003). Second, these are muscles that contribute to the grand battement due to movements defined at each joint, e.g., knee extension, ankle plantar flexion, etc.

The photographs below demonstrate the data collection for each of the eight muscles. Each position was selected to approximate a movement that would be familiar to the dance participant. Figure 1, abdominals, represents movements such as curling up from the floor (the Graham pleadings in modern dance), or recovery from falls to the floor that using a curling action to initiate movement away from the floor. Figure 2, gastrocnemius, represents plantar flexion against resistance, such as a rise onto the toes in ballet, modern, or jazz dance. The knee is slightly bent as per the Seniam guidelines for optimal muscle activation, but this is similar to the relevé used in Highland dance. Figure 3, abductor hallucis, represents the stabilization function of this muscle in pressing against the floor in any form using outward rotation in the legs, such as ballet, modern, jazz, and contemporary. Figure 4, erector spinae, represents any movement of the spine in arching, such as arabesque, in which the back works against resistance to achieve hyperextension. Many forms use arching movements of the spine (ballet, modern, African, ballroom, etc.) either with or without legs lifted to the back. Figure 5, gluteus maximus, represents any leg movement to the posterior direction, such as tendu (low leg), développé (high leg achieved slowly), or grand battement (high leg achieved quickly) to the back, or low lunges. Movements of this type can be found in almost any dance technique. Figure 6, quadriceps, represents any extension of the leg from the knee, such as a développé to the front done slowly, or a fast kick as in capoeira or jazz dance. Figure 7, hamstrings, represents movements of the lower leg lifting to the back, such as a back attitude, parallel, in modern dance or bharatanatyam. Figure 8, tibialis anterior, represents active dorsiflexion of the ankle, more commonly seen in modern and contemporary forms, or forms such as bharatanatyam, katak, flamenco dance, or urban dance that use the flexed foot.

Figure 1. Components of the PAD, showing positioning of the dancer and electrode placement during testing of the eight muscles: testing of the abdominals

Figure 2. Components of the PAD, showing positioning of the dancer and electrode placement during testing of the eight muscles: testing of the gastrocnemius

Figure 3. Components of the PAD, showing positioning of the dancer and electrode placement during testing of the eight muscles: testing of the abductor hallucis

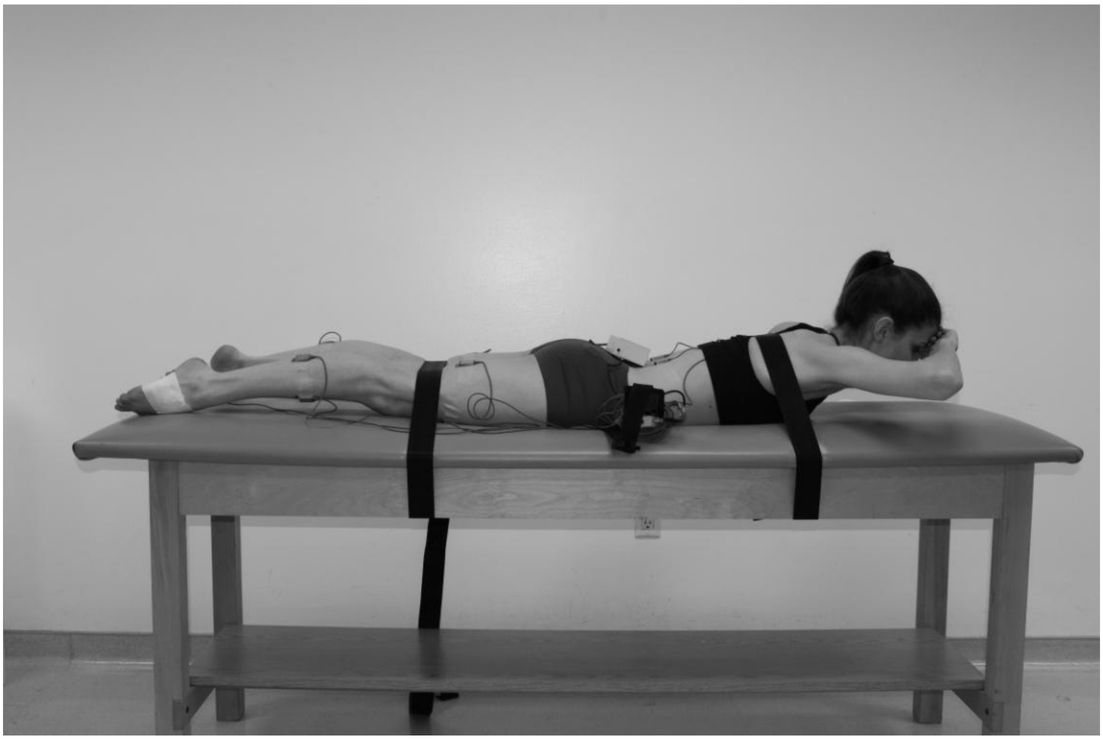

Figure 4. Components of the PAD, showing positioning of the dancer and electrode placement during testing of the eight muscles: testing of the erector spinae

Figure 5. Components of the PAD, showing positioning of the dancer and electrode placement during testing of the eight muscles: testing of the gluteus maximus

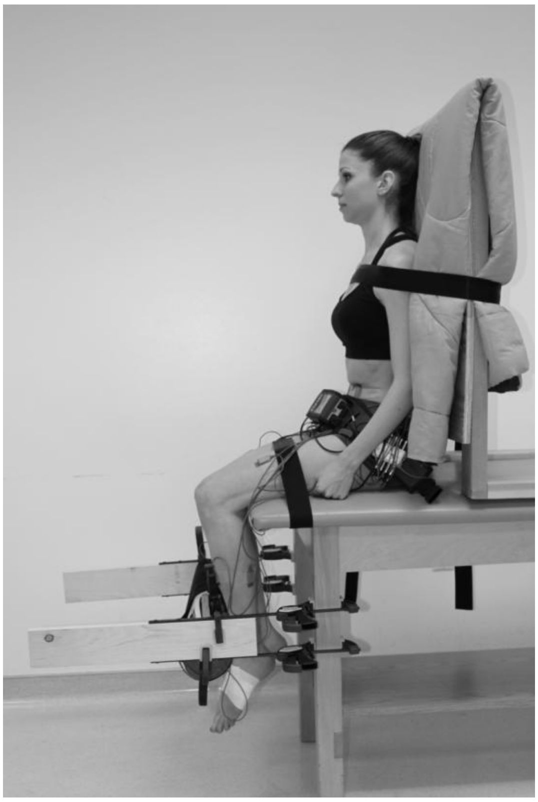

Figure 6. Components of the PAD, showing positioning of the dancer and electrode placement during testing of the eight muscles: testing of the quadriceps

Figure 7. Components of the PAD, showing positioning of the dancer and electrode placement during testing of the eight muscles: testing of the hamstrings – biceps femoris

Figure 8. Components of the PAD, showing positioning of the dancer and electrode placement during testing of the eight muscles: testing of the tibialis anterior

Electrode Placement: All participants wore sports bras and elastic shorts during the testing, and completed all trials in bare feet. Surface electrodes (DE 2.3, Myomonitor Single Differential Ag electrodes, skin contact size 10 X 1 mm, centre-to-centre distance of 10mm) were applied over the skin after it was prepped with alcohol. Electrodes placements were based on the SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) Project standards (http://www.seniam.org/). The electrodes were placed on the body in the following order: *Supine*: lateral quadriceps (QA), tibialis anterior (TA), abductor hallucis (AH), *Prone*: gastrocnemius (GA), hamstrings – biceps femoris (HA), gluteus maximus (GM), erector spinae (ES), and *Standing*: rectus abdominus (AB). This order was selected to require minimal movement during the electrode placements, so that electrodes would not be disturbed. All sEMG data were collected using a combination of a 16-channel Myomonitor IV wireless transmitter (Delsys Inc., Boston, MA) with an operating range of 25-350M, preamplifier gain 1000 V/V with a frequency bandwidth of 20-450 Hz, a common mode rejection ratio of 92dBmin at 60 Hz and an input impedance >1015Ω //0.2pF, and the Vicon Nexus 1.416 system (Centennial, CO, USA). Impedance reduces/removes extraneous noise data, that is, electrical signals not generated by muscle activation. The impedance in this study, 1015Ω //0.2pF, is the standard default impedance in the equipment used in this study, Delsys, Inc. It is selected to remove as much noise as possible, without losing signals generated by the muscles being tested. The electrode wires were wrapped around the Myomonitor belt to eliminate excess wiring that might interfere with movement and absence of crosstalk was confirmed.

Data Collection Protocol: MVICs were collected in the order listed below under Testing Order and Protocol. Note that data for AB and ES were collected bilaterally, that is, right and left sides were recorded at the same time. Data for AH, GM, QA, HA and TA were collected unilaterally, but alternating right and left, always starting with the right side for consistency. GA MVIC data were collected with all trials on the right side, then all trials on the left side, due to the complexity of moving the stabilizing straps. Joint angles for muscle testing were determined as per other previous studies in the literature using either HHD or PAD (Bohannon, 1997; Wikholm & Bohannon, 1991). Only one muscle (AH) required an investigator tester to provide manual resistance. Due to the small force provided by the AH, the possibility of a participant overpowering the investigator was ruled out. Still, to reduce inter-tester variability, the same investigator provided the resistance for all participants.

For supine position data collection, the Myomonitor belt was held off the participant's body; for prone position data collection, the wireless transmitter was not in the belt, but the belt was attached to the participant; for seated position data collection, the belt was again held just off the participant's body.

Testing Protocol and Collection Order: After electrode placement, the participant was given 15 minutes for a general warm-up. After warm-up, the investigator examined the electrodes to ensure that none had moved or dislodged. Prior to MVIC collection for each muscle, the participant was given practice trials until they informed the investigator that they were familiar with the procedure. After the practice trials, the participant performed three MVICs using the “make test” for each muscle (Bolgla & Uhl, 2007; Andrews, Thomas, & Bohannon, 1996; Bohannon, 1997), with 30 seconds rest between collections. For the ‘‘make test,’’ participants generated maximum muscle force over a 2-second period and held the maximum contraction for a 5-second period. The principal investigator provided enthusiastic verbal encouragement during all data collections (Thorborg, Petersen, Magnusson, & Hölmich, 2010). The specific positioning for each muscle can be generally seen in Figures 1-8 and is described in detail below:

Supine

1. Spine flexion - MVIC for abdominals (AB)

   The participant was supine on the table in a hook lying position, with the toes at the edge of the end of the table (hips flexed to 45 degrees and knees flexed to 90 degrees). Arms were placed at the sides of the body, and the strap crossed the chest just below both clavicles and over the humeral heads. A second strap was placed over the distal femurs, just superior to the patellae, and attached to the end of the table, parallel to the tibias. The participant attempted to flex the spine (that is, to curl the shoulders and knees together, while performing a posterior pelvic tilt). (Figure 1).

2. Ankle plantar flexion - MVIC for gastrocnemius (GA)

   The participant was supine on the table. Two straps were placed around the distal metatarsal heads and each strap was then placed over the acromioclavicular joint of each shoulder. Straps were initially tightened with the ankle in dorsiflexion so that the slack was taken up during the muscle contraction and the ankle was at 90 degrees for the MVIC. A 6” foam roller was placed under the knee, creating approximately 30 degrees of knee flexion. The participant pressed against the straps attempting to point the foot, that is, plantar flex the ankle. Participants were allowed to wear ballet slippers if they so chose. (Figure 2).

3. Big toe (hallux) abduction - MVIC for abductor hallucis (AH)

   The participant was supine on the table with a small pillow or folded towel under the head, and a foam roller under the knees for support. The participant began in full active dorsiflexion, spread the toes, and then abducted the hallux against the hand of the investigator. The investigator stabilized the participant’s heel with the other hand. (Note that some inversion may also occur and is acceptable.) (Figure 3).

Prone

4. Spine extension - MVIC for erector spinae (ES)

   The participant was prone on the table. One strap was placed over the scapulae and thoracic spine at the level of the axilla. A second strap was placed at the posterior distal femurs, superior to the knee joints. The arms were folded, hands placed under the forehead, elbows out to the side. The participant attempted to extend the spine (lift the upper torso) off the table. The arms lifted off the table, while the hands remained in contact with the forehead. Dancers were instructed to raise their torso off of the table with the greatest effort possible, and they could use the lower extremities as they saw fit. (Figure 4).

5. Hip extension - MVIC for gluteus maximus (GM)

   The participant was prone on the table. One strap was placed over the scapulae and thoracic spine at the level of the axilla. A second strap was placed at the posterior distal femurs, superior to the knee joints. A third strap was placed just above the posterior superior iliac spines (PSIS's). The arms were folded, hands placed under the forehead, elbows out to the side. The participant extended one hip with maximal effort. (Figure 5).

Seated

6. Knee extension - MVIC for quadriceps (QA)

   The participant sat off the end of the table with hips and knees flexed to approximately 90 degrees. The upper thighs were stabilized to the table by a strap placed at the mid-femurs. The trunk was stabilized to the back support by a strap across the upper trunk just below the axilla, arms relaxed at the sides of the body. The anchoring system was attached by clamps to the table legs at level of participant's lower legs, anterior to the tibia. The participant extended one knee with maximal effort. See (Figure 6).

7. Knee flexion - MVIC for hamstring (HA)

   The participant sat off the end of the table with hips and knees flexed to approximately 90 degrees. The upper thighs were stabilized to the table by a strap placed at the mid-femurs. The trunk was stabilized to the back support by a strap across the upper trunk just below the axilla, arms relaxed at the sides of the body. The anchoring system was attached by clamps to the table legs at level of participant's lower legs, posterior to the tibia. The participant flexed one knee with maximal effort. (Figure 7).

8. Ankle dorsiflexion - MVIC for tibialis anterior (TA)

   The participant sat off the end of the table with hips and knees flexed to approximately 90 degrees. The upper thighs were stabilized to the table by a strap placed at the mid-femurs. The trunk was stabilized to the back support by a strap across the upper trunk just below the axilla, arms relaxed at the sides of the body. The anchoring system was attached by clamps to the table legs at level of participant's foot, anterior to the foot, resting on the metatarsals. The participant began with the ankle in approximately 35 degrees of plantar flexion, and dorsiflexed the ankle with maximal effort, which caused the foot to push against the anchoring system with the ankle at 90 degrees. (Figure 8).

Data processing: All sEMG data were processed using Visual 3D (C-Motion Inc. Germantown, MD). The sEMG signals were first processed with a band pass filter from 10 Hz to 450 Hz, using a fourth-order, zero-lag Butterworth filter. The sEMG signals for the MVICs were then smoothed using a 99 ms wide RMS time window to obtain steady state results. Three trials for each muscle were ensemble averaged to obtain one composite representative trial for each muscle using a customized pipeline.

It should be noted that MVICs are a function of fibre length and hence joint angle. It is for this reason that to assure valid data, joint angles were selected for the

MVIC collection that are standardized and consistent across all subjects, so that there is a consistent relationship of the MVIC to the movement being executed.

3.2.2 Results.

The purpose of developing the PAD described in this thesis was to design a normalization procedure for sEMG data collection for dance-related research. In this context, the system needed to be portable for use in dance spaces, to be modified in terms of body positioning for dancers, and to provide consistent and reliable results.

All participants reported that the PAD was comfortable yet challenging. Participants also indicated that they provided their maximal effort and were pleased that the testing was performed using dance-specific positions.

Figure 9 represents a single representative MVIC data collection trial for the left gastrocnemius of one exemplar participant. The figure exhibits raw data for all eight muscles on the left side during this trial. The fourth graph in Figure 9 clearly demonstrates a specific onset and activity above baseline for the left gastrocnemius. Other active muscles in this trial include abdominals, erector spinae, and hamstrings. During the MVIC trial, it is not possible for the subject to fully isolate the single muscle being tested, in attempting to elicit a maximum contraction. Other muscles will automatically engage to stabilise the body and active limb. In the case of the gastrocnemius trial, it could be anticipated that abdominals and erector spinae would contribute to trunk stabilisation, and the hamstrings would contribute to lower extremity stabilisation.

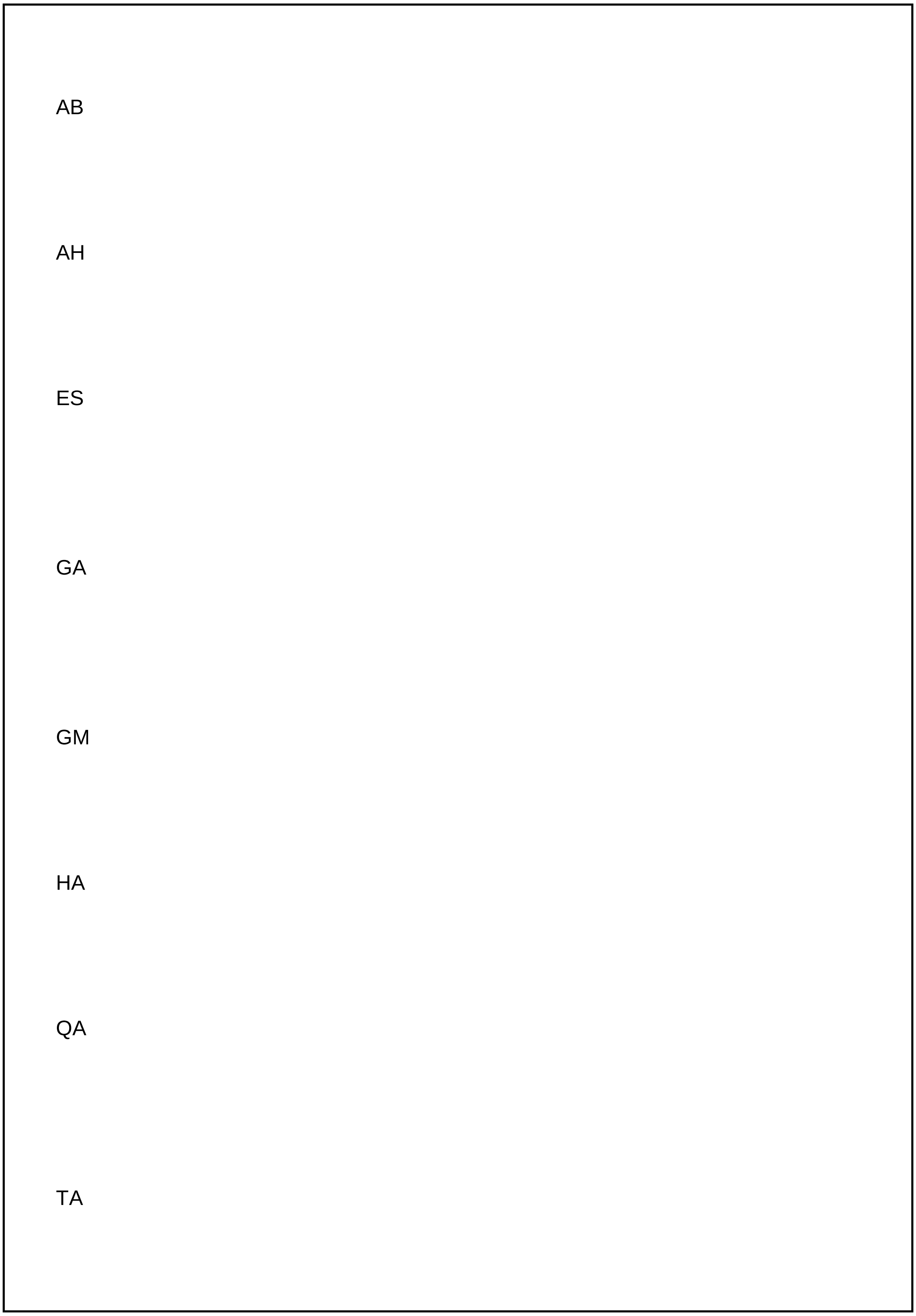

Figure 9. Left gastrocnemius trial: Raw data from sEMG recordings for AB (abdominals), AH (abductor hallucis), ES (erector spinae), GA (gastrocnemius), GM (gluteus maximus), HA (hamstrings), QA (quadriceps), and TA (tibialis anterior) muscles. X-axis is in seconds, Y-axis is in millivolts.

Figure 10 represents the conversion of raw data to filtered data for four of the muscles seen in Figure 9 during the MVIC data collection for the left gastrocnemius. The raw data is first filtered, and then the filtered data is divided by the MVIC for that muscle to arrive at the normalised data. This results in data that is stated as a percentage of maximum for each muscle, for each subject. It can be seen that the gastrocnemius (graph 1) and hamstrings (graph 2) are both active in this trial, whereas the tibialis anterior (graph 3) and abductor hallucis (graph 4) are unchanged relative to baseline. These results are consistent with what would be expected in dance trials for the gastrocnemius muscle. These graphs are representative of the graphs for the muscles tested in these pilot studies, with clear bursts of activation for the target muscle, supporting activity in muscles contributing to stabilization, and little or no activity in remaining muscles.

Note that unfiltered data has not been averaged. First the data was filtered, then an ensemble average was taken for the three MVIC trials, and then the maximum of the ensemble average was taken to establish the maximum for use in normalisation.

The sEMG measures the electrical activation level of the muscle, not force generation, and there is not a linear relationship between the sEMG signal and muscle force generation. This is precisely why normalisation is so essential.

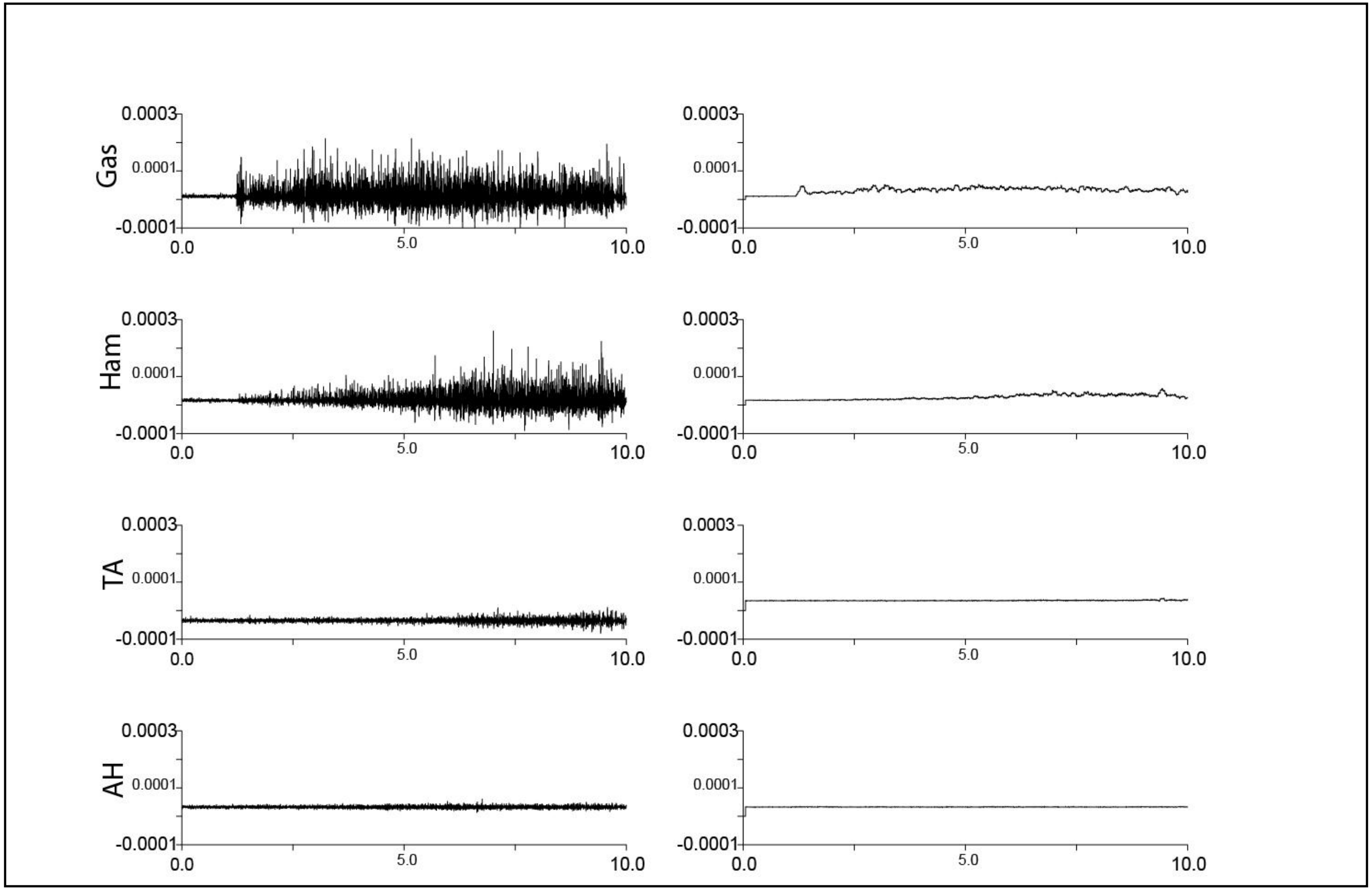

Figure 10. Left gastrocnemius trial: Raw (left) and filtered (right) data from sEMG recordings for GA (gastrocnemius), HA (hamstrings), TA (tibialis anterior), and AH (abductor hallucis). X-axis is in seconds, Y-axis is in millivolts.

Figure 11 represents all three MVIC trials for the left gastrocnemius for the same participant with the bolded line being the average of the three trials. Again, this graph is representative of the three-trial and average graphs for the tested muscles in the pilot study. The individual trial lines and the bolded average line are similar to results found in previous literature. They demonstrate the general consistency of our PAD across the three trials, as well as within each trial. Although repeated trials in a second testing session were not conducted due to time constraints, these results suggest consistency with this procedure for single-session testing.

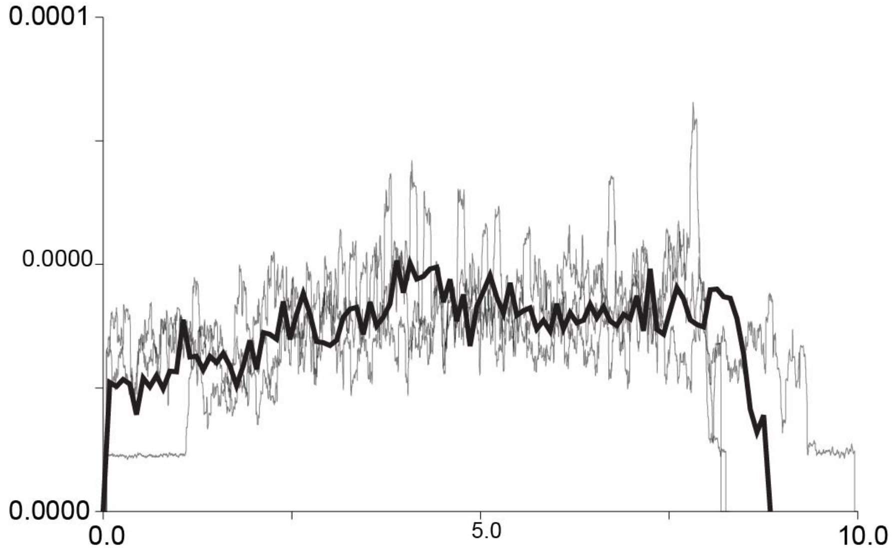

Figure 11. Left gastrocnemius trial: three MVIC trials and ensemble graph. This graph shows the composite data of the three trials, with the bold line showing the average. X-axis is in seconds, Y-axis is in millivolts.

CHAPTER FOUR

GRAND BATTEMENT STUDY

[portions of this chapter have been published in *Medical Problems of Performing Artists]*

Krasnow, D., Ambegaonkar, J. P., Wilmerding, M. V., Stecyk, S., Koutedakis, Y., & Wyon, M. (2012). Electromyographic Comparison of Grand Battement Devant at the Barre, in the Centre, and Traveling. *Medical Problems of Performing Artists, 27*(3), pp. 143-155*.*

Krasnow, D., Wilmerding, M. V., Stecyk, S., Wyon, M., & Koutedakis Y. (2012). Examination of weight transfer strategies during the execution of grand battement devant at the barre, in the centre, and traveling. *Medical Problems of Performing Artists, 27*(2), pp. 74-84*.*

4.1 Introduction

As principal investigator, I was responsible for every aspect of the study. I began by developing the research questions and overall design of the research. I was present and actively participated in every lab set-up, calibration, and data collection for all forty subjects. While I used the assistance of professional statisticians, I participated in developing the approaches to analyses, and to all of the interpretation. Additionally I involved the aid of two dance science consultants. Dr. Wilmerding consulted on some of the dance-related questions, such as whether to use first or fifth position for barre and centre trials, and Dr. Ambegaonkar consulted on some of the issues related to sEMG collections, and my understanding of collecting, filtering, and normalising the data.

The development of the PAD in Chapter Three allowed for the normalisation of the sEMG data, so that the muscle amplitudes could be compared across subjects during the grand battement trials. The next phase of the research involved the data collection of the kinematic data and sEMG data during the grand battement in the three conditions, at the barre, in the centre, and traveling. Kinematic and sEMG data were collected at the same time for each subject.

4.2 Methods

4.2.1 Participants.

Dancers were recruited for the study through announcements in university dance classes and postings in professional dance email listservs and local newsletters. Forty-three female dancers volunteered for the study. Inclusion criteria included enrolment in a university level dance class or in a professional dance studio or training program, and exposure to ballet and/or modern dance. Exclusion criteria included a history of confounding medical problems or a current injury impacting on the execution of the dance task for the study. The study was approved by the Standing Advisory Committee for the Protection of Human Subjects at California State University, Northridge, and all participants gave informed written consent. One volunteer arrived with a recent injury and was excluded from the study. Data for two participants had to be eliminated from analysis due to lost data during collection. The remaining forty participants had a mean age 30.0 ± 13.0 yrs, mean height 1.63 ± 0.06 m, mean mass 59.0 ± 7.4 kg, and 13.9 ± 13.3 yrs of training in ballet and/or modern dance. The three levels for the study were defined by two dance experts as follows: (1) Beginning dancers (n = 12) had less than two years of training, mean 1.5 ± 0.5 years; (2) Intermediate dancers (n = 14) had more than two years of training, mean 11.9 ± 9.6 years, and no professional (paid) dance experience; (3) Advanced dancers (n = 14) had 10 or more years of training, mean 25.5 ± 11.4 years, and professional (paid) dance experience. No differentiation was made between the terms elite, advanced, and professional dancers. Dance experience included ballet, modern and contemporary dance, jazz, hip hop, break or street dance, musical theatre, tap dance, and various world dance forms. Dancers from various professional dance companies were included.

4.2.2 Instrumentation.

Kinematic data were collected with a 7-camera Vicon MX Ultranet motion capture system (Oxford Metrics Ltd, Oxford, UK), with 35 spherical markers using a Plug-in Gait Full Body Marker set, sampled at 240 Hz. Markers were placed bilaterally at the acromio-clavicular joint, the lateral epicondyle of the elbow, the dorsum of the hand just below the head of the second metacarpal, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), lateral mid-femur below the level of the hand, lateral epicondyle of the knee, lateral mid-calf, lateral malleolus of the ankle, second metatarsal head on the midfoot side of the equinus break between the forefoot and midfoot, calcaneus at the same height as the toe marker, and unilaterally at the jugular notch where the clavicles meet the sternum, xiphoid process of the sternum, spinous process of the seventh cervical vertebra, spinous process of the tenth thoracic vertebra, and the middle of the right scapula. Additionally the participant wore a headband around the skull just above the ears, with two anterior markers located approximately over the right and left temple and two posterior markers placed on the back of the head approximately in the horizontal plane with the front markers, and wristbands with markers on the thumb and pinkie sides as close to the wrist joint centre as possible (Figure 12). Comparisons of the Vicon system to other motion analysis systems have shown it to be accurate and reliable (Richards, 1999). The motion capture system was calibrated at the beginning of each day of data collection. Reconstruction, labelling and gap filling were done in Nexus 1.6.1.57351 and the filtering and kinematic scripts were completed in Visual 3D v4.75.36 (C-Motion Inc, Germantown, Maryland).

There are four possible sources of error in motion analysis data collection. First, there is possible error in taking the anthropomorphic measurements of the subject. This can be reduced through practice previous to actual trials, and by having the same researcher do the measurements. Second, there is possible error in placement of the reflective markers, which again can be reduced by having the same researcher do these placements. Third, there is potential error in calibration of the system, which is kept within certain standardized parameters. Fourth, there is potential error through movement of the skin or clothing.

Figure 12. Participant with 35 spherical markers
using a Plug-in Gait Full Body Marker set

Surface electrodes (DE 2.3, Myomonitor Single Differential Ag electrodes, skin contact size 10 X 1 mm, centre-to-centre distance of 10mm) were applied over the skin after it was prepped with alcohol. Electrode placements were based on the SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) Project standards (http://www.seniam.org/). The electrodes were placed on the body in the following order: *Supine*: quadriceps (QA), tibialis anterior (TA), abductor hallucis (AH), *Prone*: gastrocnemius (GA), biceps femoris (HAM), gluteus maximus (GM), erector spinae (ES), and *Standing*: rectus abdominus (ABS). This order required the least amount of participant movement, which limited the possibility of electrode disturbance during the process. All sEMG data were collected using a combination of a 16-channel Myomonitor IV wireless transmitter (Delsys Inc., Boston, MA) with an operating range of 250m, preamplifier gain 1000 V/V with a frequency bandwidth of 20-450 Hz, a common mode rejection ratio of 92dBmin at 60 Hz and an input impedance >1015Ω //0.2pF, and the Vicon Nexus 1.416 system (Centennial, CO, USA). Impedance reduces/removes extraneous noise data, that is, electrical signals not generated by muscle activation. The impedance in this study, 1015Ω //0.2pF, is the standard default impedance in the equipment used in this study, Delsys, Inc. It is selected to remove as much noise as possible, without losing signals generated by the muscles being tested. The electrode wires were wrapped around the Myomonitor belt to eliminate excess wiring that might interfere with movement. Data for maximum voluntary isometric contractions (MVICs) were collected with a portable anchoring dynamometer system developed for the purposes of this study, described in Chapter 3 (Krasnow, Ambegaonkar, Stecyk, Wilmerding, Wyon, & Koutedakis, 2011). Kinetic data were collected with two Kistler forceplates (9287A, 9287BA) (Kistler Instruments, Inc., Amherst, New York) at 960 Hz.

4.2.3 Protocol for data collection of grand battement trials.

All participants wore sports bras and elastic shorts during testing, and completed all trials in bare feet. After surface electrodes were placed on the body, dancers completed a self-selected warm up of 15 minutes, followed by the MVIC collection, using previously published methods (Krasnow, Ambegaonkar, Stecyk, Wilmerding, Wyon, & Koutedakis, 2011). Dancers were then given a 15-minute resting interval, and a second warm-up period, before the movement trial procedure was explained. Trials at the barre and in the centre were executed in the dancer's preferred first position, lower extremities externally rotated. While most of the external rotation comes from the hip joint, there are also contributions from the knee, ankle and foot, and the subjects were allowed to establish their usual first position. All trials were conducted with the right leg as the gesture leg. Dancers performed 5 trials at the barre in 1st position with the left hand at the barre, 5 trials in the centre in 1st position, and 5 trials traveling. See Appendix A for photographs of the various conditions and events. An order for the 15 trials was determined randomly, and all participants followed the same randomized order, with 1-minute rest periods between trials. First position was used at the barre and in the centre, as it allowed for a more direct comparison between the three conditions. For barre and centre trials, dancers were instructed to hold the final stance position until instructed by the researchers to rest. Traveling trials included two steps (right, left) prior to the battement and two steps (right, left) after the battement. Steps were executed in plié at a depth of the dancer's choice, and dancers were instructed to take the first step onto forceplate 1 and the second step onto forceplate 2, with the final two steps clearing the forceplate area. While these instructions permitted some variance due to height and leg length, the size of the forceplates encouraged large steps. In essence, the traveling condition simulates the preparation for a grand jeté, an elevation step in dance that is initiated with a grand battement during a traveling step, followed by a landing on the opposite leg. Trials were executed in time to a recording of the music titled Dance of the Knights from the ballet *Romeo and Juliet* by Sergei Prokofiev at a tempo of 104 beats per minute. At the barre, the left hand was resting on the barre, and the right arm was in classical second position. For the centre and traveling trials, both arms were in classical second position.

4.2.4 Definitions of variables (body regions) and events.

Four variables were defined as body regions: Centre of Gravity of the Full Trunk (from a midline between the sternum and C7 markers to a midline between the hip joints); Centre of Gravity of the Pelvis; Centre of Gravity of the Upper Trunk (from a midline between the sternum and C7 markers to a midline between ASIS and PSIS markers); and Centre of Mass. Visual 3D automatically calculates Centre of Gravity of the Pelvis and Centre of Mass. Data for the x-axis represented lateral or frontal plane movement, and by convention, positive numbers were movement to the right and negative numbers were movement to the left. Data for the y-axis represented sagittal plane movement, and by convention, positive numbers were movement forward and negative numbers were movement backward. The data from the z-axis (the axis that is perpendicular to the x-axis and the y-axis) was not considered for analysis, but was used in identifying events. Four events were defined for evaluation: Stance (STN), Grand Battement Initiation (GBI), Grand Battement Peak (GBP), and End (END).

For the Barre and Centre conditions, the events were defined as follows:

Stance (STN) is 120 samples or frames (0.5 seconds) prior to the GBI.

Grand Battement Initiation (GBI) is the point in time when the velocity of the right heel marker starts moving in the forward (y-axis) direction. When the y-component of first derivative (velocity) of the right heel is greater than 0, it indicates that the right heel is moving in the forward direction.

Grand Battement Peak (GBP) is the highest point in the z-axis for the right toe marker.

End (END) is 120 samples or frames (0.5 seconds) after the point in time when the weight shifts from being entirely on the left foot back onto the right foot after the grand battement.

For the Traveling condition, the events were defined as follows:

Stance (STN) is the point in time when all of the weight is transferred onto the left foot prior to the grand battement, marked by toe off on the back forceplate (forceplate 1). At this point the right leg is behind the left leg but is not weight-bearing.

Grand Battement Initiation (GBI) is the point in time when the right heel passes the left heel in the y-direction, as the right leg moves forward to initiate the battement.

Grand Battement Peak (GBP) is the highest point in the z-axis for the right toe marker.

End (END) is 120 samples or frames (0.5 seconds) after the point in time when the weight shifts entirely off the left foot onto the right foot after the grand battement, marked by toe off on the front forceplate (forceplate 2).

4.3 Section 1: Kinematic data

4.3.1 Statistical Analyses.

Differences in the distances between pairs of the four events were calculated (STN to GBI, GBI to GBP, and GBP to END), and these three distance measures were called intervals. Means and standard deviations for each participant and for all participants combined for the four variables and for the three intervals were calculated. Table 1 shows the means and standard deviations for variables and intervals for all participants combined in centimetres. Separate repeated measures ANOVAs (3:Condition X 3:Interval) were conducted for each variable in each axis, with Training level as a between-subjects factor. Where significant main effects were observed, a Bonferroni procedure was conducted to determine where significant differences occurred. Analysis was set at .05 alpha level. Bonferroni adjusts for Type 1 error, so no further adjustments to the alpha level were necessary. All reported p values are the adjusted p values based on the Bonferroni procedure.

Table 1. Means and standard deviations in cm for distance of weight transfer for COG Full Trunk, COG Pelvis, COG Upper Trunk, and COM for three intervals: Stance to Initiation, Initiation to Peak, Peak to End, for all subjects combined.

x-axis (lateral movement)	Stance to Initiation		Initiation to Peak		Peak to End	
	Mean	SD	Mean	SD	Mean	SD
Full Trunk						
Barre	-2.21	1.13	-2.80	1.62	3.75	1.90
Centre	-2.71	0.99	-3.32	1.84	6.01	2.26
Traveling	-1.29	0.99	0.75	1.20	1.39	2.05
Pelvis						
Barre	-2.08	1.01	-2.48	1.89	3.50	2.13
Centre	-2.46	1.05	-3.02	2.14	5.58	2.37
Traveling	-1.16	1.29	0.60	1.67	1.24	2.28
Upper Trunk						
Barre	-2.19	1.15	-3.74	1.75	4.61	2.06
Centre	-2.88	1.07	-4.42	2.03	7.21	2.47
Traveling	-2.29	0.96	-0.14	1.27	2.01	2.31
Centre of Mass						
Barre	-1.96	0.98	-2.77	1.38	3.62	1.75
Centre	-2.50	.088	-3.28	1.74	5.76	2.06
Traveling	-1.18	0.99	0.48	1.07	1.03	2.10

y-axis (sagittal movement)	Stance to Initiation		Initiation to Peak		Peak to End	
	Mean	SD	Mean	SD	Mean	SD
Full Trunk						
Barre	-0.99	1.35	-2.93	2.04	4.52	2.19
Centre	-0.49	1.74	-1.54	1.71	4.83	1.64
Traveling	12.20	11.52	22.15	4.83	41.75	32.45
Pelvis						
Barre	-0.34	1.70	0.97	3.33	0.11	3.36
Centre	0.19	2.18	1.73	2.97	0.82	2.87
Traveling	13.45	10.95	22.09	4.90	35.31	31.30
Upper Trunk						
Barre	-1.03	1.52	-5.52	1.78	7.22	1.93
Centre	-0.76	1.66	-3.72	1.88	7.27	1.86
Traveling	11.22	11.62	20.83	4.60	44.56	32.89
Centre of Mass						
Barre	-0.49	1.32	0.78	1.72	0.31	2.02
Centre	0.23	1.93	1.92	1.39	0.45	1.39
Traveling	14.57	11.39	22.62	4.31	36.37	34.29

In the x-axis, positive numbers are weight shift to the right, negative numbers are weight shift to the left. In the y-axis, positive numbers are weight shift forward, negative numbers are weight backward.

4.3.2 Results.

The main effect Condition was significant for all four variables (COG Full Trunk, COG Pelvis, COG Upper Trunk, and Centre of Mass) in both the x-axis and the y-axis at $\alpha = .05$. There were no significant differences for Training and no significant Condition x Training interactions. Because training was not a significant factor, data was collapsed across the three training levels, as seen in Table 1.

Further, Condition was significant for all three intervals (STN to GBI, GBI to GBP, and GBP to END) for all four variables in both axes at $\alpha = .05$, using the Greenhouse-Geisser adjustment. The p values for the four variables (Full Trunk, Pelvis, Upper Trunk, and Centre of Mass) for all three intervals (Stance to Initiation, Initiation to Peak, and Peak to End) in both x-axis and y-axis are represented in Table 2.

Table 2. Significance levels (F values, degrees of freedom, and p values) for the COG Full Trunk, COG Pelvis, COG Upper Trunk, and COM, for all three intervals (STN to GBI, GBI to GBP, and GBP to END) in both axes at α = .05.

Body region variables	Axis	Interval	df values Numerator	df values Denominator	F value	p value
Full Trunk	x-axis	STN to GBI	1.7	64.7	21.527	.000
	x-axis	GBI to GBP	1.8	65.2	153.973	.000
	x-axis	GBP to END	1.6	59.5	76.539	.000
	y-axis	STN to GBI	1.0	37.6	48.226	.000
	y-axis	GBI to GBP	1.1	42.3	1310.464	.000
	y-axis	GBP to END	1.0	37.1	50.084	.000
Pelvis	x-axis	STN to GBI	1.7	64.0	16.120	.000
	x-axis	GBI to GBP	1.7	61.7	106.817	.000
	x-axis	GBP to END	1.5	54.5	65.445	.000
	y-axis	STN to GBI	1.0	38.0	58.763	.000
	y-axis	GBI to GBP	1.1	42.2	797.989	.000
	y-axis	GBP to END	1.0	37.1	47.323	.000
Upper Trunk	x-axis	STN to GBI	1.9	70.0	5.427	.007
	x-axis	GBI to GBP	1.8	66.8	150.705	.000
	x-axis	GBP to END	1.6	57.9	80.973	.000
	y-axis	STN to GBI	1.0	37.6	41.053	.000
	y-axis	GBI to GBP	1.2	44.2	1298.643	.000
	y-axis	GBP to END	1.0	37.1	49.686	.000
Centre of Mass	x-axis	STN to GBI	1.8	65.0	21.678	.000
	x-axis	GBI to GBP	1.7	63.6	159.080	.000
	x-axis	GBP to END	1.5	55.0	78.238	.000
	y-axis	STN to GBI	1.0	37.7	62.380	.000
	y-axis	GBI to GBP	1.1	42.0	1062.695	.000
	y-axis	GBP to END	1.0	37.1	43.515	.000

Because Condition for each Interval was significant for all four variables in both axes as reported in Table 2, a Bonferroni procedure was conducted to compare barre to centre, barre to traveling, and centre to traveling at each interval and in each axis. The p values of condition pairwise comparisons for the four variables (Full Trunk, Pelvis, Upper Trunk, and Centre of Mass) for all three intervals (Stance to Initiation, Initiation to Peak, and Peak to End) in both x-axis and y-axis are represented in Table 3.

Table 3. Significance levels (p values) for condition pairwise comparisons for COG Full Trunk, COG Pelvis, COG Upper Trunk, and COM for three intervals: Stance to Initiation, Initiation to Peak, Peak to End.

x-axis		STN to GBI	GBI to GBP	GBP to END
Full Trunk	Barre to Centre	.028	**.060**	.000
	Barre to Traveling	.002	.000	.000
	Centre to Traveling	.000	.000	.000
Pelvis	Barre to Centre	**.149**	.038	.000
	Barre to Traveling	.004	.000	.000
	Centre to Traveling	.000	.000	.000
Upper Trunk	Barre to Centre	.003	.020	.000
	Barre to Traveling	**1.00**	.000	.000
	Centre to Traveling	.036	.000	.000
COM	Barre to Centre	.006	**.050**	.000
	Barre to Traveling	.005	.000	.000
	Centre to Traveling	.000	.000	.000
y-axis		STN to GBI	GBI to GBP	GBP to END
Full Trunk	Barre to Centre	.034	.000	**.505**
	Barre to Traveling	.000	.000	.000
	Centre to Traveling	.000	.000	.000
Pelvis	Barre to Centre	**.086**	.005	.009
	Barre to Traveling	.000	.000	.000
	Centre to Traveling	.000	.000	.000
Upper Trunk	Barre to Centre	**.485**	.000	**1.00**
	Barre to Traveling	.000	.000	.000
	Centre to Traveling	.000	.000	.000
COM	Barre to Centre	.006	.000	**1.00**
	Barre to Traveling	.000	.000	.000
	Centre to Traveling	.000	.000	.000

Note: The nine non-significant p-values are in bold.

4.3.2.1 Stance to Initiation, x-axis.

In the x-axis, Stance to Initiation demonstrated significant differences for all three conditions (barre, centre and traveling) for COG of the Full Trunk. As the dancers began to initiate the grand battement, they shifted the Full Trunk 2.2 cm to the left at the barre, 2.7 cm to the left in the centre, and only 1.2 cm to the left while traveling. For the COG of the Pelvis in this first phase, barre and centre were not significantly different (p = .149), but traveling was significantly different from the other two conditions. The Pelvis shifted 2.1 cm to the left at the barre, 2.5 cm to the left in the centre, and only 1.2 cm to the left while traveling. The COG of the Upper Trunk shift was similar between barre and traveling (p = 1.00), but centre was significantly different from both barre and from traveling. The Upper Trunk shifted 2.2 cm to the left in this movement phase at the barre, 2.9 cm in the centre, and 2.3 cm traveling. Finally, as with the Full Trunk, the COM of the full body demonstrated significant differences for all three conditions, shifting to the left 2.0 cm at the barre, 2.5 cm in the centre, and 1.2 cm while traveling. Figure 13 graphically displays the mean distances from Stance to Initiation in the x-axis, broken down by body region and condition.

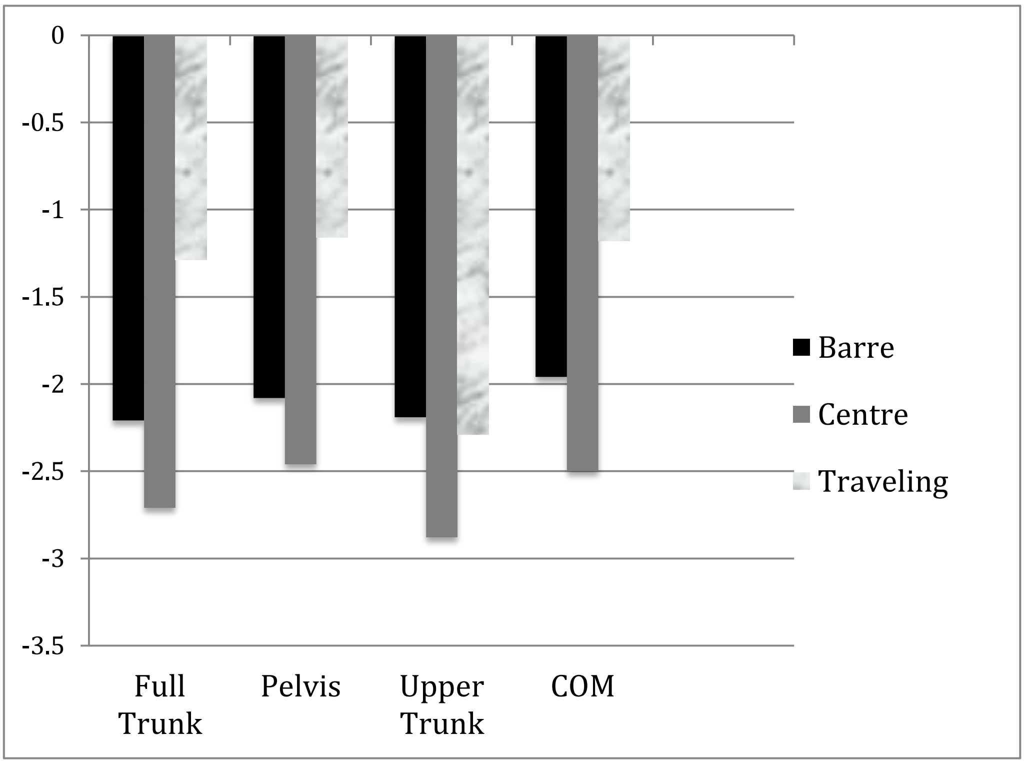

Figure 13. Distance from Stance to Initiation in the x-axis in cm
COG Full Trunk, COG Pelvis, COG Upper Trunk, COM

4.3.2.2 Initiation to Peak, x-axis.

In this second phase, Initiation to Peak, traveling was significantly different from barre and centre for all variables. The Full Trunk shifted 2.8 cm to the left at the barre, 3.3 cm left in the centre, and 0.8 cm to the right for the traveling condition. For the Full Trunk, barre was not significantly different from centre in this phase, but there is a trend towards significance (p = .06). For both the Pelvis and the Upper Trunk, all three conditions were significantly different. The shift of the Pelvis was 2.5 cm to the left at the barre, 3.0 cm to the left in the centre, and 0.6 cm to the right while traveling. For the Upper Trunk, the shift was 3.7 cm to the left at the barre, 4.4 cm to the left in the centre, and 0.1 cm to the left traveling. For the COM, barre and centre were not significantly different, but as with the Full Trunk there is a trend towards significance (p = .05). The shift was 2.8 cm to the left at the barre, 3.3 cm to the left in the centre, and 0.5 cm to the right for traveling. It was noted that the Upper Trunk was the only variable that demonstrated a shift to the left in the traveling condition during this phase. The other three body regions shifted to the right in this phase. Figure 14 graphically displays the mean distances from Initiation to Peak in the x-axis, broken down by body region and condition.

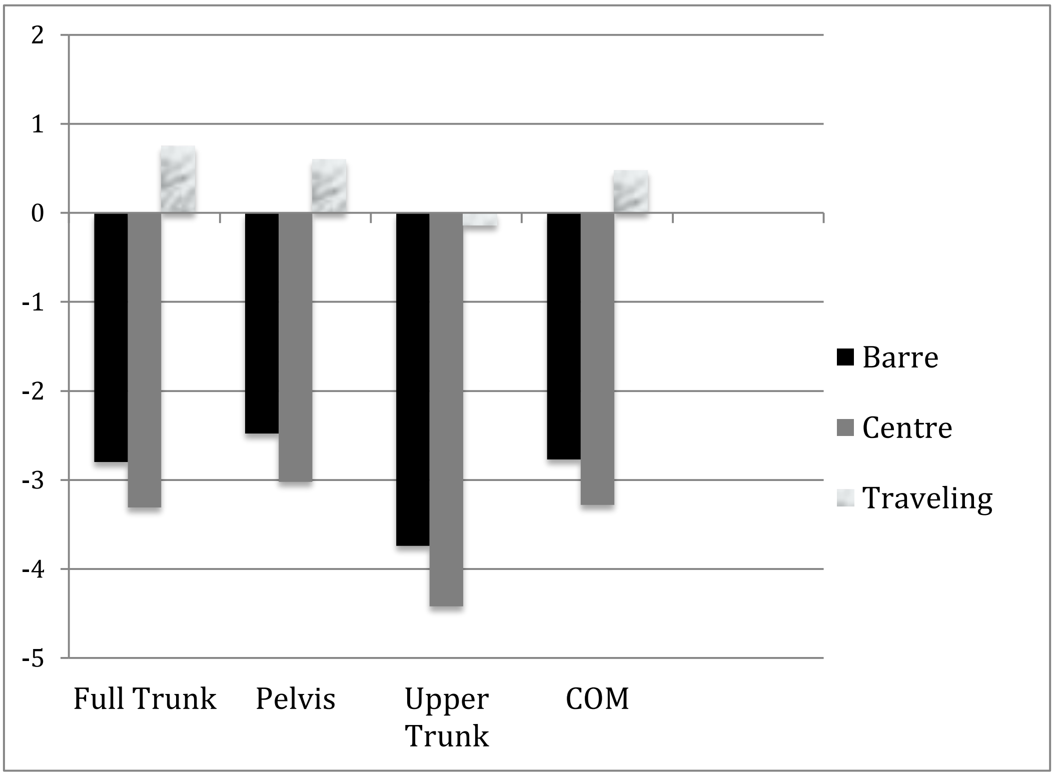

Figure 14. Distance from Initiation to GB Peak in the x-axis in cm
COG Full Trunk, COG Pelvis, COG Upper Trunk, COM

4.3.2.3 Peak to End, x-axis.

For Peak to End, all variables again demonstrated significant differences between all conditions for all variables. For Full Trunk, the shift was 3.7 cm to the right at the barre, 6.0 cm to the right in the centre, and 1.4 cm to the right while traveling. For the Pelvis, the shift was 3.5 cm to the right at the barre, 5.6 cm to the right in the centre, and 1.2 cm to the right while traveling. For the Upper Trunk, the shift was 4.6 cm to the right at the barre, 7.2 cm to the right in the centre, and 2.0 cm to the right while traveling. And for the COM, the shift was 3.6 cm to the right at the barre, 5.8 cm to the right in the centre, and 1.0 cm to the right while traveling. Figure 15 graphically displays the mean distances from Peak to End in the x-axis, broken down by body region and condition. It can be observed that the Upper Trunk does the largest amount of lateral movement in this phase for all three conditions.

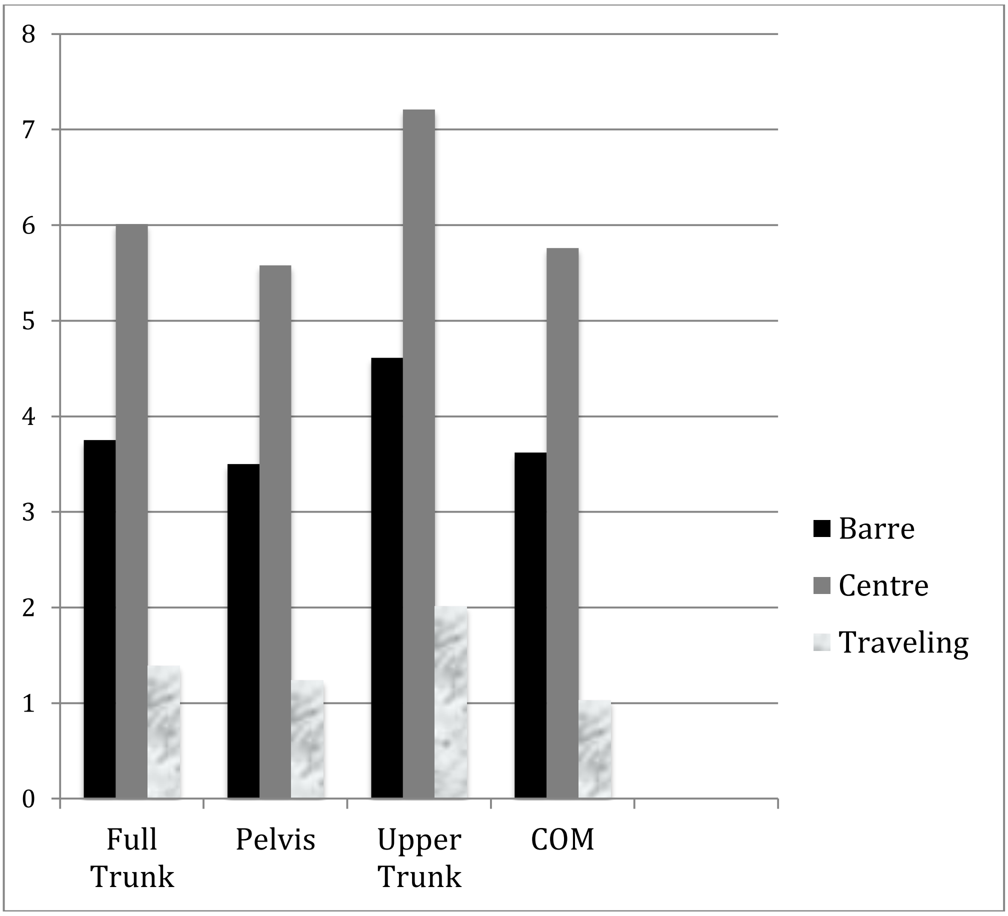

Figure 15. Distance from GB Peak to End in the x-axis in cm
COG Full Trunk, COG Pelvis, COG Upper Trunk, COM

4.3.2.4 Stance to Initiation, y-axis.

Similar to the x-axis, most variables in the y-axis demonstrated significant difference for all conditions, in all three movement phases, with several shifts occurring in the backward direction. The exception to this backward shift was for all body regions of the traveling condition, in which all shifts were forward, and for Pelvis and COM for the centre condition. During Stance to Initiation in the y-axis, for the Full Trunk, all three conditions differed significantly. The shift was 1.0 cm backward at the barre, 0.5 cm backward in the centre, and 12.2 cm forward in the traveling condition. For the Pelvis, barre and centre were not significantly different ($p = .086$), but traveling differed significantly from the other two conditions. The shift for the Pelvis was 0.3 cm backward at the barre, 0.2 cm forward in the centre, and 13.4 cm forward in the traveling condition. For the Upper Trunk, again barre and centre were not significantly different ($p = .485$), but traveling was significantly different from the other two conditions. The shift for Upper Trunk was 1.0 cm backward at the barre, 0.8 cm backward in the centre, and 11.2 cm forward in the traveling condition. Finally, as with the Full Trunk, the COM of the full body demonstrated significant differences for all three conditions; the shift was 0.5 cm backward at the barre, 0.2 cm forward in the centre, and 14.6 cm forward in the traveling condition. Figure 16 graphically displays the mean distances from Stance to Initiation in the y-axis, broken down by body region and condition.

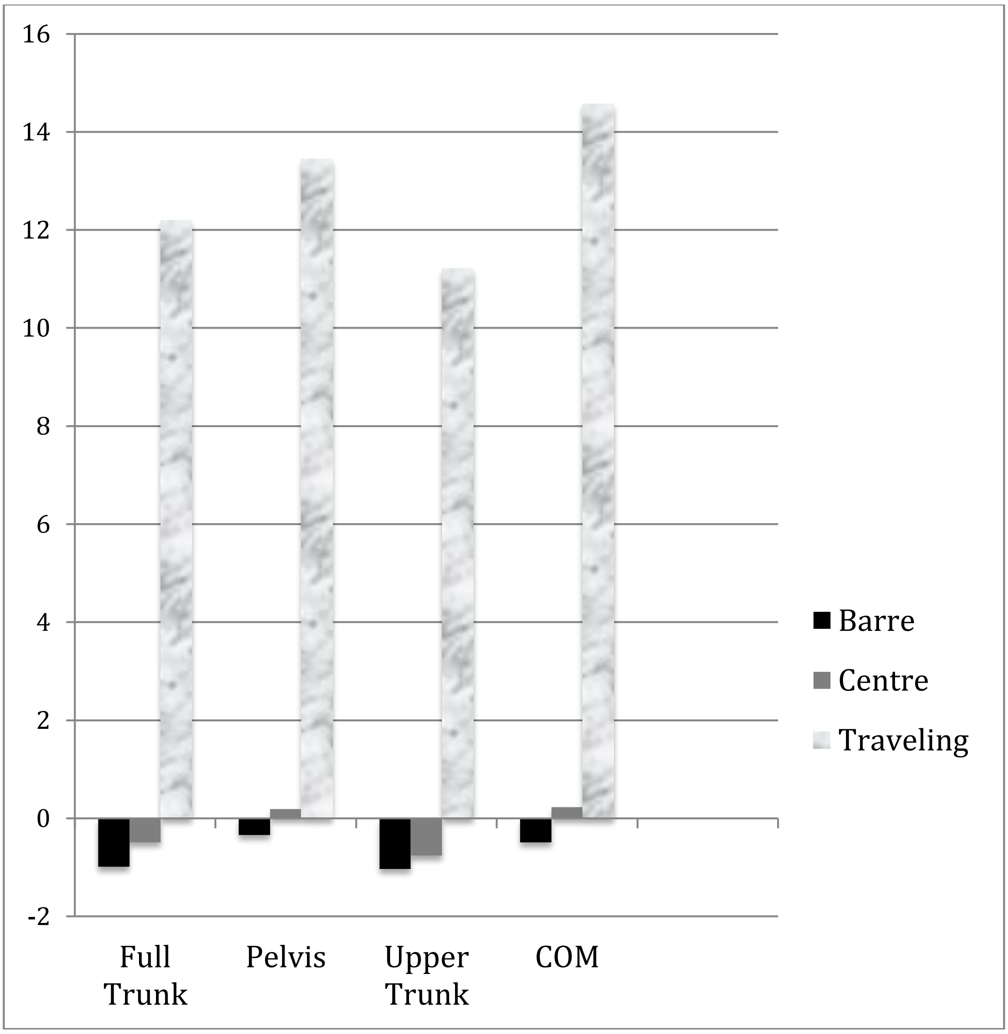

Figure 16. Distance from Stance to Initiation in the y-axis in cm
COG Full Trunk, COG Pelvis, COG Upper Trunk, COM

4.3.2.5 Initiation to Peak, y-axis.

For Initiation to Peak, all variables demonstrated significant differences between all conditions. For the Full Trunk, the shift was 2.9 cm backward at the barre, 1.5 cm backward in the centre, and 22.1 cm forward in the traveling condition. For the Pelvis, the shift was 1.0 cm forward at the barre, 1.7 cm forward in the centre, and 22.0 cm forward in the traveling condition. For the Upper Trunk, the shift was 5.5 cm backward at the barre, 3.7 cm backward in the centre, and 20.8 cm forward in the traveling condition. And for the COM, the shift was 0.8 cm forward at the barre, 1.9 cm forward in the centre, and 22.6 cm forward in the traveling condition.

Figure 17 graphically displays the mean distances from Initiation to Peak in the y-axis, broken down by body region and condition.

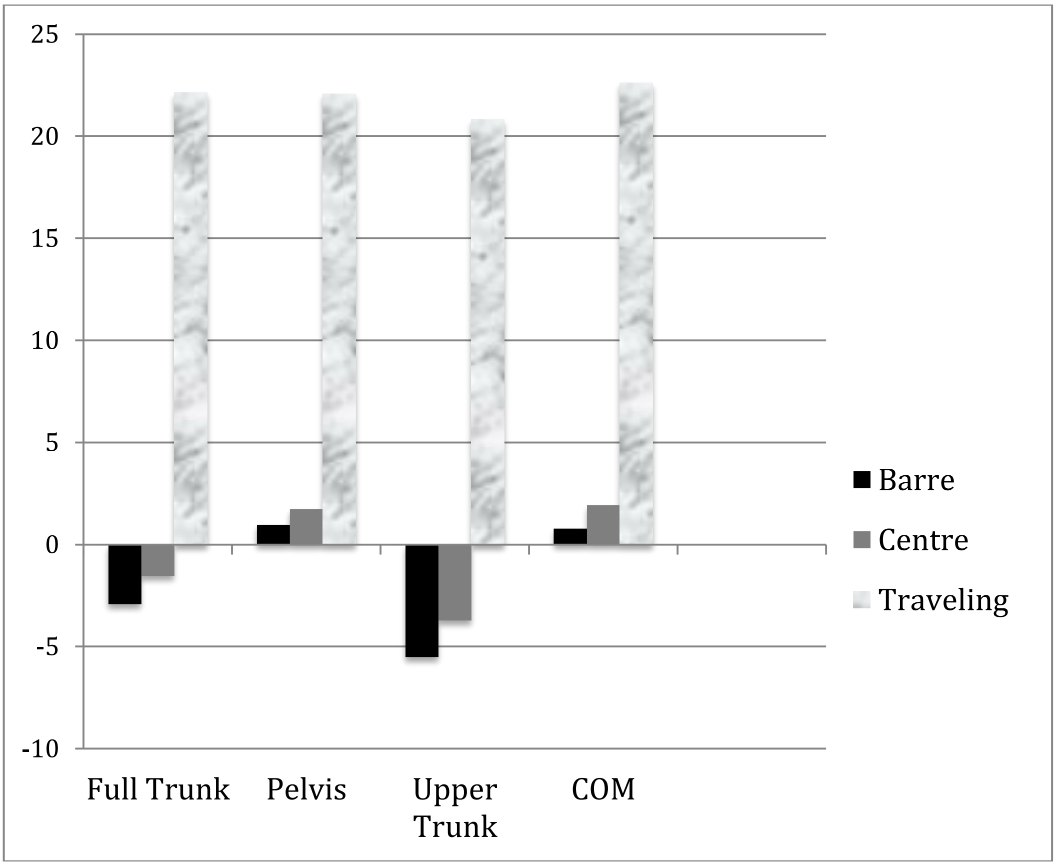

Figure 17. Distance from Initiation to GB Peak in the y-axis in cm
COG Full Trunk, COG Pelvis, COG Upper Trunk, COM

4.3.2.6 *Peak to End, y-axis.*

In the y-axis, barre and centre most closely resembled each other in this last movement phase, with the Pelvis demonstrating the only significant difference between these two conditions. For the Full Trunk p = .505, for the Upper Trunk p = 1.00, and for the COM p = 1.00. However, traveling was significantly different from the other two conditions for all four body regions. All weight shift was forward in this last phase. For Full Trunk, the shift was 4.5 cm at the barre, 4.8 cm in the centre, and 41.7 cm in the traveling condition. For the Pelvis, the shift was 0.1 cm at the barre, 0.8 cm in the centre, and 35.3 cm in the traveling condition. For the

Upper Trunk, the shift was 7.2 cm at the barre, 7.3 cm in the centre, and 44.6 cm in the traveling condition. And for the COM, the shift was 0.3 cm at the barre, 0.5 cm in the centre, and 36.4 cm in the traveling condition. Figure 18 graphically displays the mean distances from Peak to End in the y-axis, broken down by body region and condition.

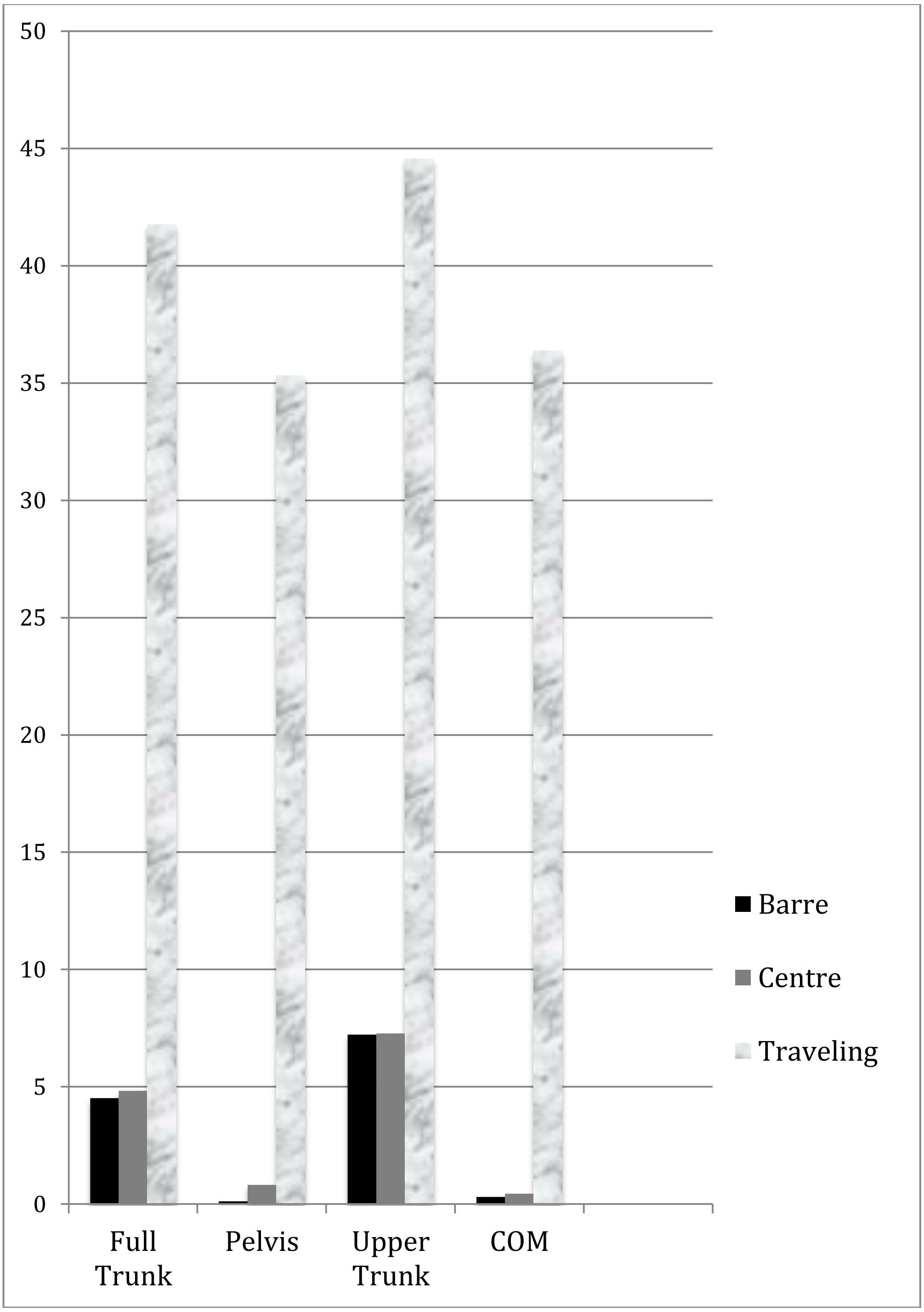

Figure 18. Distance from GB Peak to End in the y-axis in cm
COG Full Trunk, COG Pelvis, COG Upper Trunk, COM

4.3.3 Discussion.

It is interesting to note that there were no significant differences for the weight transfer data due to level of training in the results of this study. For this reason, the training level data has not been included. It is likely that dancers with different levels of training vary in the aesthetics of movement execution, and this has been noted in other research (Kwon, Wilson, & Ryu, 2007; Monasterio, Chatfield, Jensen, & Barr, 1994; Mouchnino, Aurenty, Massion, & Pedotti, 1992; Wilson, Lim, & Kwon, 2004). For example, Mouchnino (1992) found that the advanced dancers used a translation strategy to shift the pelvis onto the supporting leg from stance on two feet, while the novices used an inclination strategy. In this study, the research question involved the amount of transfer executed, looking at various body segments, and for this question, no differences in training levels were exhibited. Further inquiry into the joint angles might uncover differences in the three groups of dancers.

Overall it can be stated that although dancers are often instructed to maintain the full trunk as a unit during weight transfer, it was not uncommon in this study for the dancers to use different motor strategies for the upper trunk and the pelvis. Further, in most intervals, there are clear differences in amount and direction of weight transfer in the three conditions, barre, centre and traveling.

4.3.3.1 Stance to Initiation, x-axis.

It can be seen that the shift towards the supporting foot was greater in the centre than at the barre for all four body regions (reaching statistical significance for all but the Pelvis) in the Stance to Initiation phase. At the barre, each region shifted a similar amount, from 2.0 cm to 2.2 cm, whereas in the centre, the range of values was from 2.5 to 2.9 cm. This result supports previous research in 5th position work, which demonstrated more sagittal shift, or movement towards the supporting foot, in the centre than at the barre (Ryman & Ranney, 1978/79). The traveling condition had the smallest values in shift to the supporting foot, with Full Trunk, Pelvis and COM at 1.2 cm, but Upper Trunk at 2.3 cm, which is why it is not significantly different from the barre in this phase. It seems that the momentum of traveling forward reduces overall lateral shift onto the supporting foot during the Stance to Initiation phase, but dancers use a strategy of moving the upper trunk in that direction to accommodate the movement.

4.3.3.2 Initiation to Peak, x-axis.

There is considerable similarity in values between Full Trunk, Pelvis and COM in the Initiation to Peak phase in the x-axis. It is for the Upper Trunk that dancers use a very different strategy during this phase of the movement. The shifts at the barre and centre are greatest for the Upper Trunk, and it is only for this variable that the shift in the traveling condition is to the left.

It is also noteworthy to observe how different the strategy is for the traveling condition from Stance to Peak, relative to what is occurring at barre and centre. During the Stance to Initiation phase, while traveling, the weight shifted to the left for all variables, but as the leg moved from Initiation to Peak, the weight started to shift back to the right (except for the Upper Trunk), in preparation for shifting the weight onto the gesture leg after the battement. In other words, even before the gesture leg had reached peak, the weight was already starting its shift towards the leg that would become the new support. At the barre and centre, the weight continues its transfer towards the supporting leg throughout both of these first two phases.

4.3.3.3 Peak to End, x-axis.

If the values for Stance to Initiation and Initiation to Peak are added, and compared to Peak to End, there is a pattern that can be observed across all variables, when examining barre and centre. At the barre, the shift to the left in the first half of the movement was 5.0 cm for the Full Trunk, but the return from peak to end was only 3.7 cm to the right. For the Pelvis the shift was 4.6 cm to the left, and the return was 3.5 cm to the right. For the Upper Trunk, the shift was 5.9 cm to the left, and the return was 4.6 cm to the right. Finally, for the COM, the shift was 4.8 cm to the left, and the return was 3.6 cm to the right. In each case, the dancer did not return to the starting position, that is, after the battement was completed, the centre of gravity of the various body regions remained further towards the barre than prior to the battement.

However, for the centre condition, the pattern was quite different. For the Full Trunk, the shift in the first half of the movement was 6.0 cm to the left, and the return was 6.0 cm to the right. For Pelvis, the shift was 5.5 cm to the left, and the return was 5.6 cm to the right. For the Upper Trunk, the shift was 7.3 cm to the left and the return was 7.2 cm to the right. And for the COM, the shift was 5.8 cm to the left and the return was 5.8 cm to the right. In each instance, the dancer returned to the starting (stance) position after the battement. It would seem counter-productive to practice this movement repeatedly at the barre, and train the body to fail to return to a place with the weight centred on both feet, if it is to have application to unsupported movement.

It is of interest to note in general how small the values were in the x-axis for all conditions and intervals for the traveling condition. While dancers spend considerable time learning how to shift onto the supporting leg, once the body began traveling in the forward direction, very little shift to the supporting leg, i.e., the base of support, occurred. The act of moving forward appears to entail little time spent in balance on either foot, and if the body were to stop moving at any point in the movement sequence, it would fall sideways as well as forward. Finally, the Upper Trunk displayed the largest movement in all three phases, for all variables. Further, during the traveling condition, the Upper Trunk and Pelvis moved in opposite directions in the Initiation to Peak phase. Despite instructions to dancers to maintain these two body regions as a unified segment, as the leg is rising in grand battement devant there was clearly a difference in upper trunk and pelvic motion during this movement.

4.3.3.4 Stance to Initiation, y-axis.

Although the values are small in the Stance to Initiation phase in the y-axis, it is interesting to note that in the centre condition, the Full Trunk and Upper Trunk moved backward in this first phase, while the Pelvis and COM shifted forward. At the barre, however, all four variables indicated movement backward. It may be that in the unsupported condition, there is a counterbalance occurring in the upper trunk and pelvis that is not needed at the barre.

4.3.3.5 Initiation to Peak, y-axis.

In the Initiation to Peak phase, for the Full Trunk and the Upper Trunk, barre and centre were significantly different from each other even though the shift was backward for both. The Pelvis and COM moved forward for both barre and centre, which were also significantly different. Hence it is the quantity and not the direction of shift that made barre and centre differ significantly for all body regions in this movement phase. Further, the Full Trunk and Upper Trunk shifted more at the barre than in the centre, but the Pelvis and COM shifted less at the barre. Therefore, both quantity of shift, and strategy and direction for the various regions of the body differentiate barre and centre in this phase of the movement.

4.3.3.6 Peak to End, y-axis.

From Peak to End, the Pelvis and COM make little shift forward in either the barre or centre condition, compared to the movement of the Full Trunk and Upper Trunk. Although alignment was not a focus of this study, it is possible that the trunk is leaning back at the initiation of the battement and moves forward as the body follows through from Peak to End to accomplish the weight transfer onto the new supporting foot. Additional study would be needed to verify this strategy.

Again it is of interest to compare the shift in the first half of the movement (Stance to Peak) to the return (Peak to End) for barre and centre. At the barre, for the Full Trunk the shift backward in the first half of the movement was 3.9 cm, but the return from Peak to End was 4.5 cm forward. For the Pelvis the shift was 0.7 cm forward in the first half, and the return was 0.1 cm further forward. For the Upper Trunk, the shift was 6.5 cm backward, and the return was 7.2 cm forward. Finally, for the COM, the shift was 0.3 cm forward, and the return was 0.3 cm further forward. In each case, the dancer ended slightly further forward than they began. The differences are 0.6, 0.8, 0.7, and 0.6.

For the centre condition, the pattern is similar in that the dancers ended further forward, but the quantity is larger. For the Full Trunk, the shift in the first half of the movement was 2.0 cm backward, and the return was 4.8 cm forward. For Pelvis, the shift was 1.9 cm forward, and the return was 0.8 cm further forward. For the Upper Trunk, the shift was 4.5 cm backward and the return was 7.3 cm forward. And for the COM, the shift was 2.1 cm forward and the return was 0.5 cm further forward. For this condition the differences are 2.8, 2.7, 2.8, and 2.6.

What is striking is how similar the differences from start to finish were for the four variables in each condition. For the barre the range is 0.6 to 0.8 cm, and for the centre condition, the range is 2.6 to 2.8 cm. Despite differences observed during phases of the movement for these variables, overall each body region (Full Trunk, Pelvis, Upper Trunk and the COM) ends further forward from where it began, and at approximately the same distance per condition.

For the travelling condition, as might be expected, large changes are occurring in the forward direction throughout the movement. It is worth noting that the distance traveled from Stance (when the weight first shifted onto the left foot in preparation for the battement) to Initiation was just over half the distance covered from Initiation (when the right heel passed the left heel as it begins to leave the floor for the battement) to Peak. This indicates that even though the right leg is doing a high forward kick, which would involve momentum in the z-axis, the pelvis and weight center are still traveling forward considerably. This movement, the traveling battement, is preparation for grand jeté, and the strategies learned at the barre and in the centre are not similar to the movement execution in traveling. At the barre and in the centre, the weight is not attempting to transfer forward in space.

4.4 Section 2: EMG data

4.4.1 Statistical Analyses.

Data for the analyses were computed by dividing muscle output data by the MVIC for each muscle for each participant. For example, 0.48 indicated that the participant used 48% of her maximum during that movement.

In order to identify which data points needed to be removed from the sample due to measurement error and/or due to too much influence as an outlier, the Mahalanobis distance was utilized. The Mahalanobis distance is best for non-independent data as in this study, as it takes into account the covariance among the variables and measures the distance in three dimensions (Shi & Chen, 2008). A chi-square test was used to remove all data points with a statistically significant result as outliers. With this criterion, 200 data points were removed from the sample of 7680 data points.

The hypotheses were tested using five measures: side of the body, level of training, muscle, event, and condition. Since these measures were taken from a sample of 40 dancers, the points do not meet the assumption of independence of errors. To account for this, the data were analysed using a linear mixed effects regression model. As the distribution of the dependent variable did not meet the normality assumption, the analysis was conducted using the log of the dependent variable.

The linear mixed effects regression model used the variables side, muscle, level, event, and condition as the fixed effects and side of the body and subject as the random effects. In addition, all two-, three-, four-, and five-way interactions of the main effects were tested for significance. A random slope was also retained in the model. The parameter estimation was done using the Restricted Maximum Likelihood (REML) and the model selection process was done using the Maximum Likelihood. The model that best fit the data and answered the research question was the model that predicted the dancer's muscle use using the fixed effects of a three-way interaction of level by side by muscle and a three-way interaction of muscle by event by condition. To test the significance of the individual parameters and the effects of their interactions, Wald tests using a two-side t-distribution were conducted. Analysis was set at .05 alpha level.

4.4.2 Results.

Table 4 shows muscle activation variables for all muscles, events, and conditions in all participants. It clearly illustrates that the standard deviations (SD) are relatively large in our data. This is an indication that there is a large amount of variation between dancers. We controlled for these differences between individuals within our model, and it should also be noted that our results are generalizations and that individual dancers are all unique.

Table 4. Muscle Activation Variables for All Muscles, Events, and Conditions in all participants

Variable		Average Score	SD		Average Score	SD
Muscle	L ABS	.21	.20	R ABS	.27	.43
	L AH	.49	.62	R AH	.27	.30
	L ES	.12	.16	R ES	.12	.13
	L GA	.47	.34	R GA	.24	.31
	L GM	.35	.50	R GM	.10	.10
	L HAM	.26	.25	R HAM	.11	.09
	L QA	.27	.23	R QA	.34	.32
	L TA	.24	.18	R TA	.14	.13
Event	Stance	0.15	0.17			
	Initiation	0.23	0.21			
	Peak	0.30	0.25			
	End	0.18	0.19			
Condition	Barre	0.16	0.18			
	Centre	0.18	0.15			
	Travel	0.31	0.25			

All muscle activation data are expressed as a percentage of Maximum Voluntary Isometric Contractions

Rectus Abdominus (ABS), Abductor Hallucis (AH), Erector Spinae (ES), Gastrocnemius (GA), Gluteus Maximus (GM), Biceps Femoris (HAM), Quadriceps (QA), and Tibialis Anterior (TA)

Left side (L), Right side (R)

Table 5 depicts the linear mixed effects regression model examining muscle activation for all muscles, events, and conditions in all participants. It is clear from the model that the way a dancer uses the muscles varies according to the combination of event and condition being executed. There was a significant effect for muscle X event X condition, $p < .01$. Thus, how the dancer uses each muscle is significantly different in each event and how the dancer uses each muscle within that event is significantly different in each condition. Additionally, there was a significant effect for level X side X muscle, $p < .01$. Therefore, the differences are influenced by the level of training of the dancer and the side of the body being used.

Table 5. Linear Mixed Effects Regression Model examining muscle activation for all muscles, events, and conditions in all participants

Variable		Beta	Std Error	t-value	p-value
Side		0.02	0.04	0.53	0.59
Level		0.05	0.02	2.56	0.01
Muscle		0.02	0.01	1.90	0.06
Event		0.03	0.01	2.58	0.01
Condition		0.19	0.01	13.47	0.00
Level x Side		-0.04	0.02	-2.77	0.01
Level x Muscle		-0.03	0.01	-5.30	0.00
Muscle x Event		0.01	0.01	0.82	0.41
Muscle x Condition		0.01	0.01	-0.26	0.79
Level x Side x Muscle		0.01	0.01	3.25	0.00
Muscle x Event x Condition		0.01	0.01	4.83	0.00

Figures 19-34 display the graphs the EMG activity of each muscle by side for the four events, three conditions, and three training levels. Graphs show the activity as a percentage of MVIC (maximum voluntary isometric contraction). The lines indicate the change of EMG activity from barre to centre to traveling across the four events. Training levels are represented by the three lines in each graph.

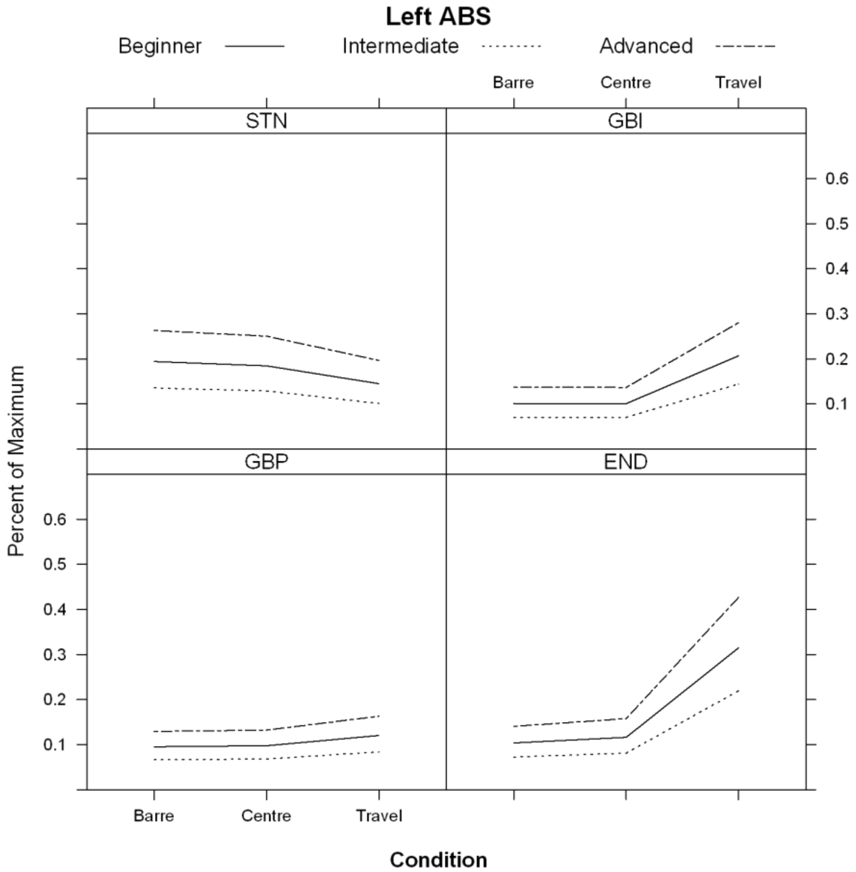

Figure 19. Left ABS by condition by event by level

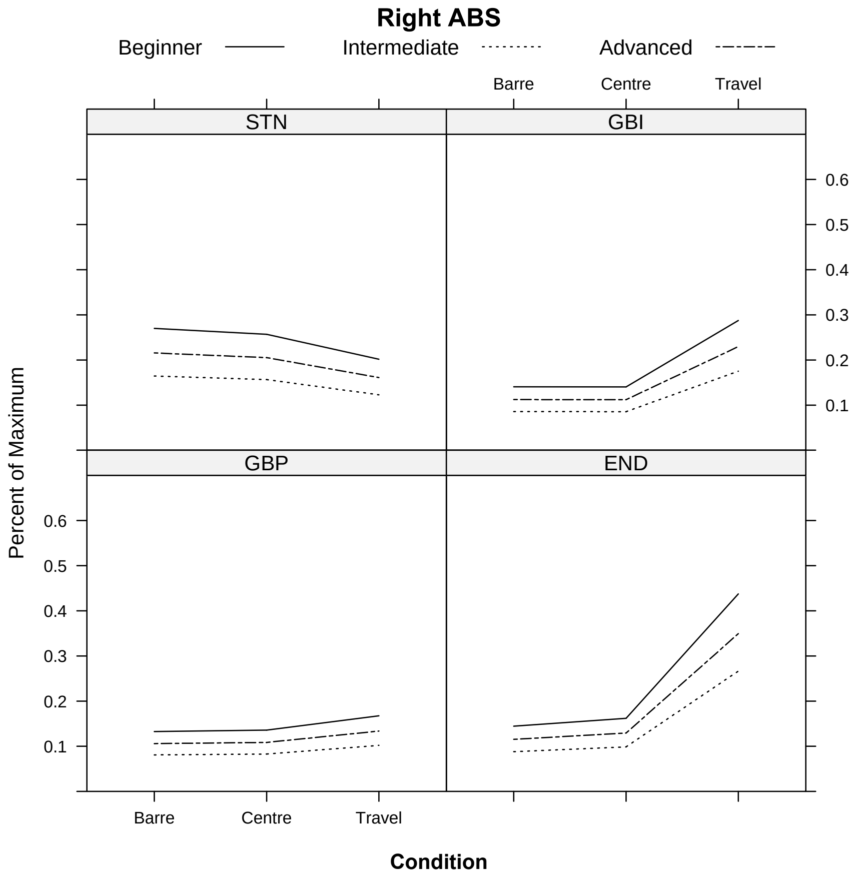

Figure 20. Right ABS by condition by event by level

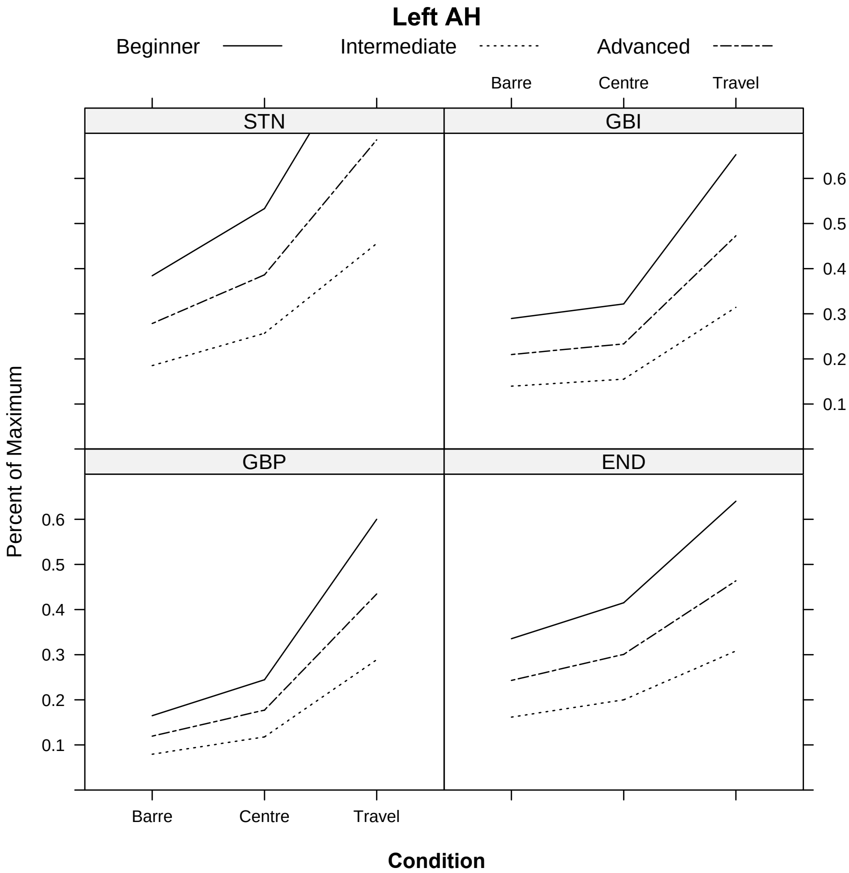

Figure 21. Left AH by condition by event by level

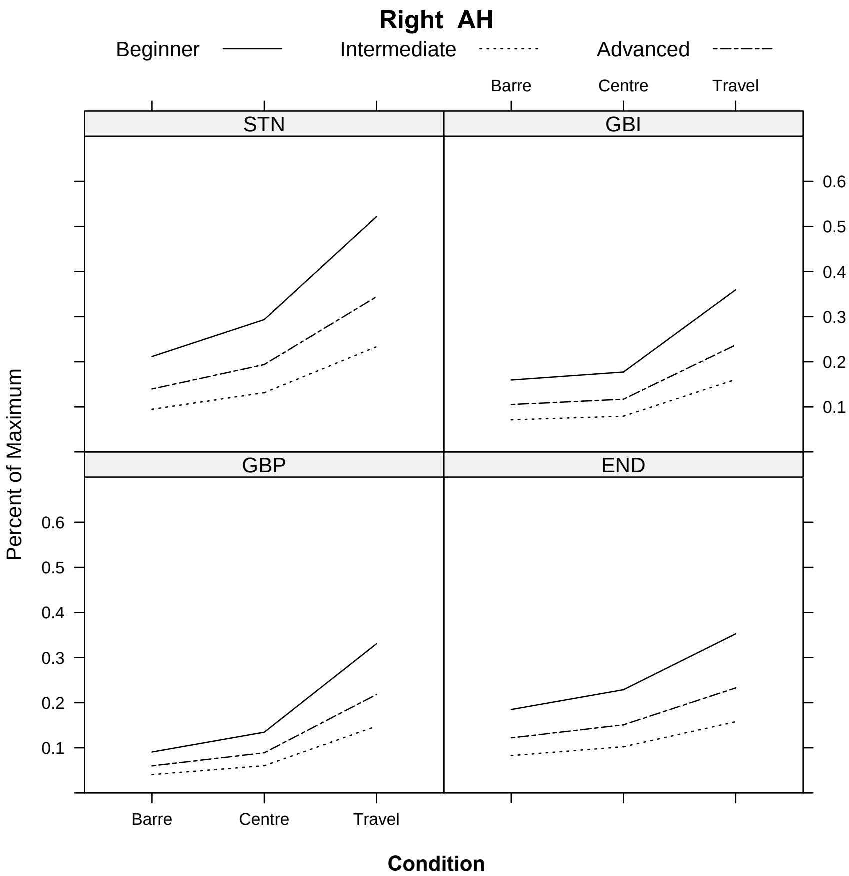

Figure 22. Right AH by condition by event by level

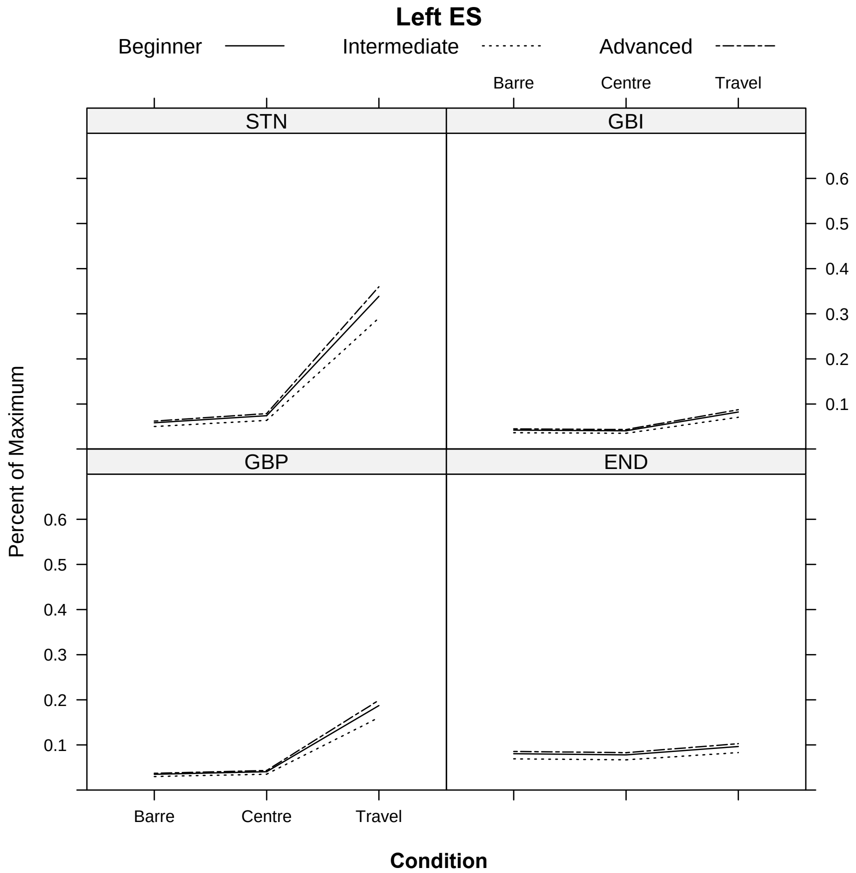

Figure 23. Left ES by condition by event by level

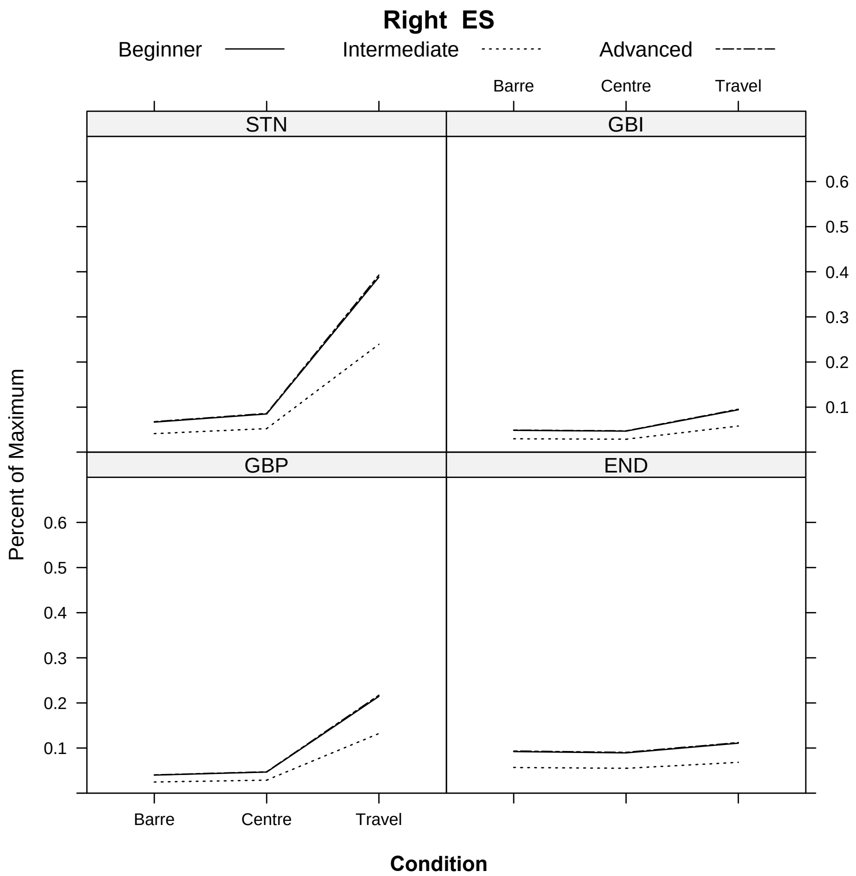

Figure 24. Right ES by condition by event by level

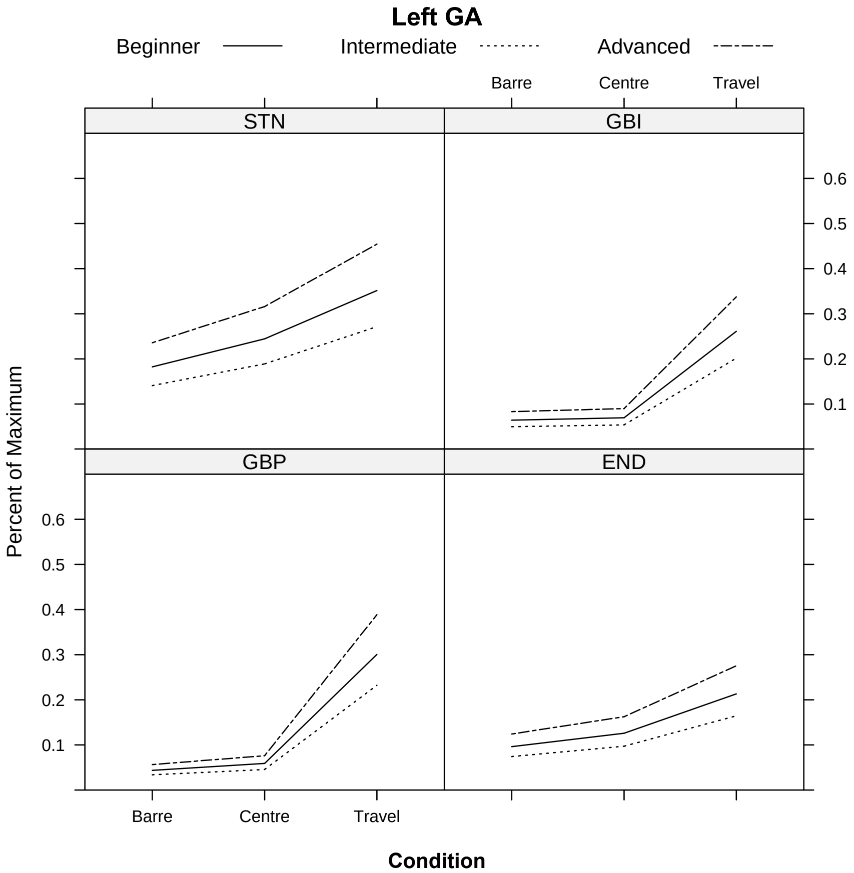

Figure 25. Left GA by condition by event by level

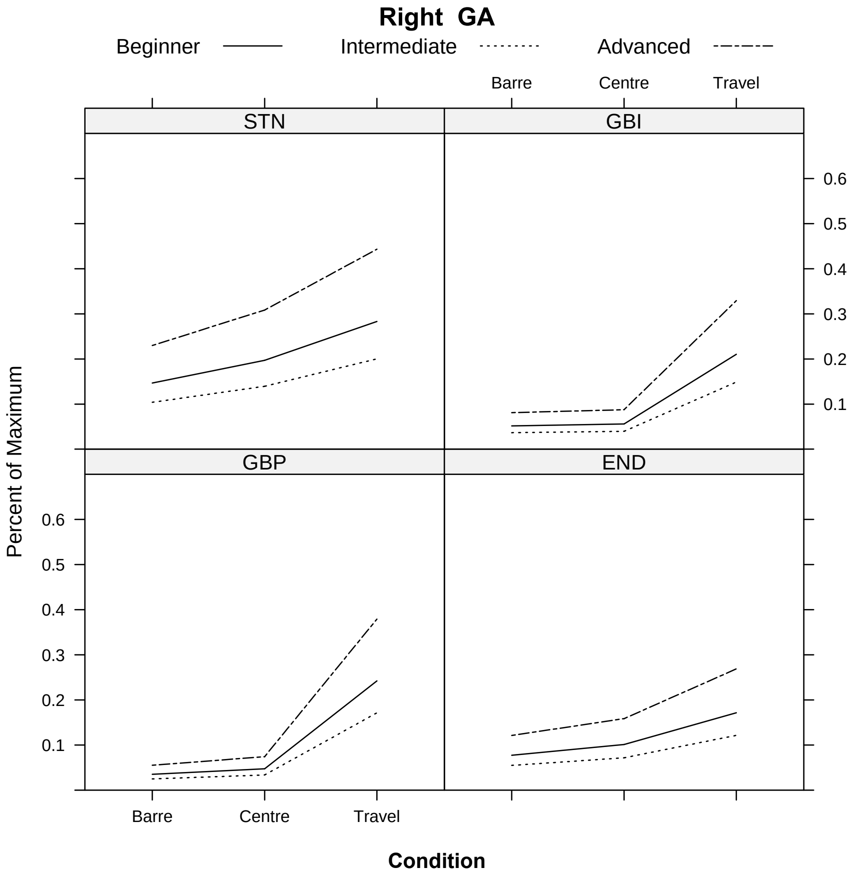

Figure 26. Right GA by condition by event by level

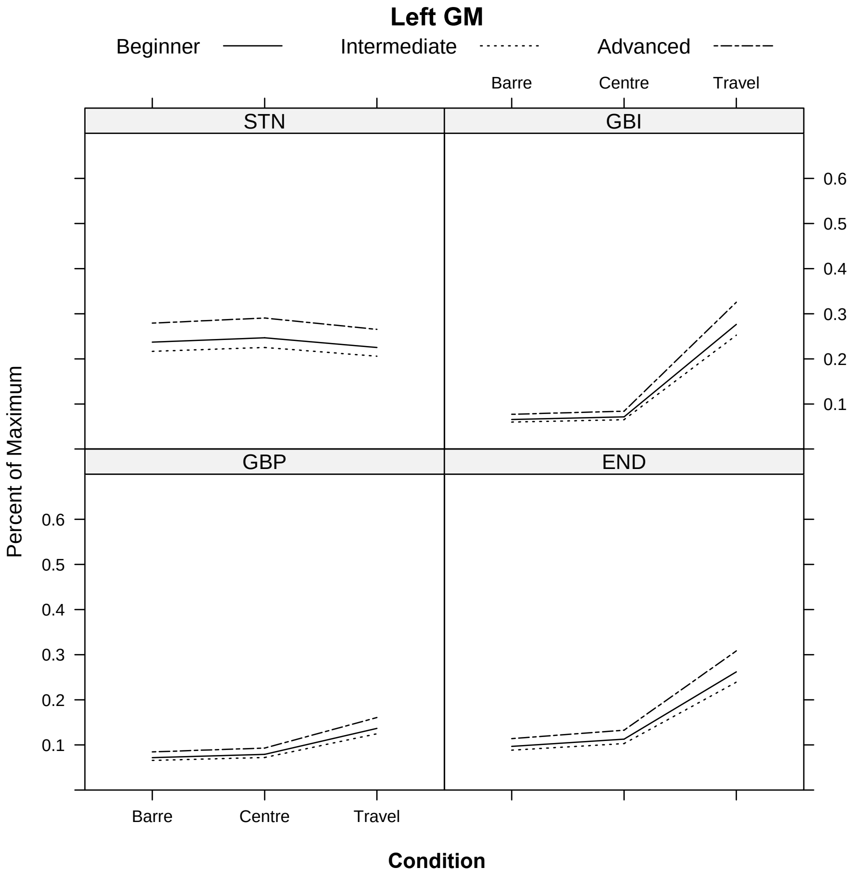

Figure 27. Left GM by condition by event by level

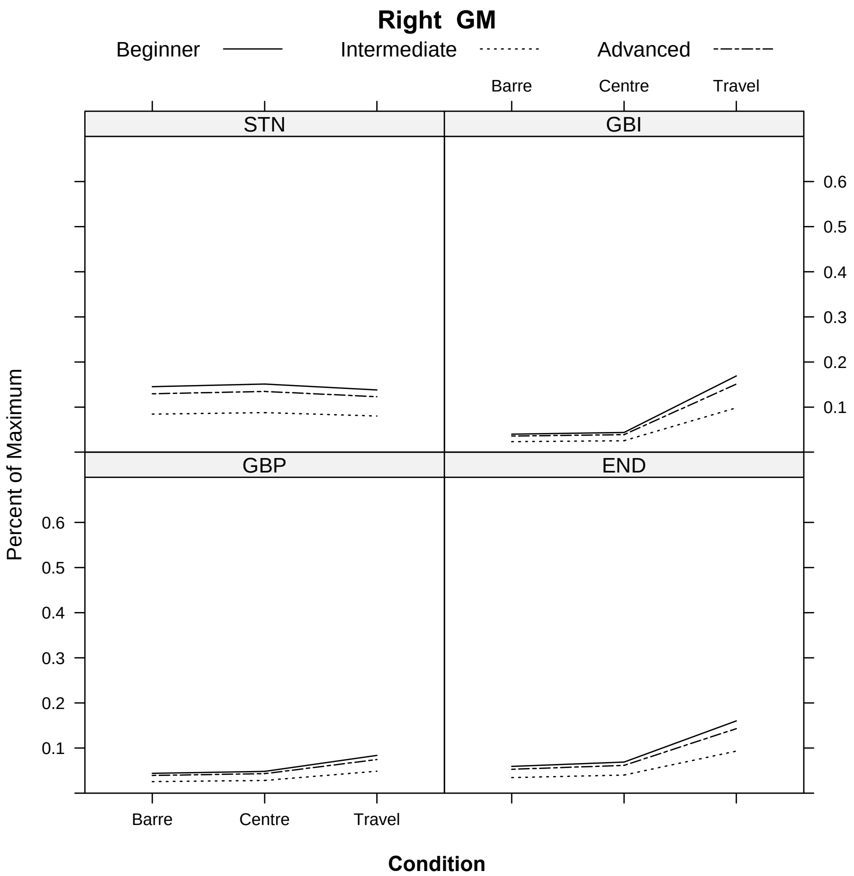

Figure 28. Right GM by condition by event by level

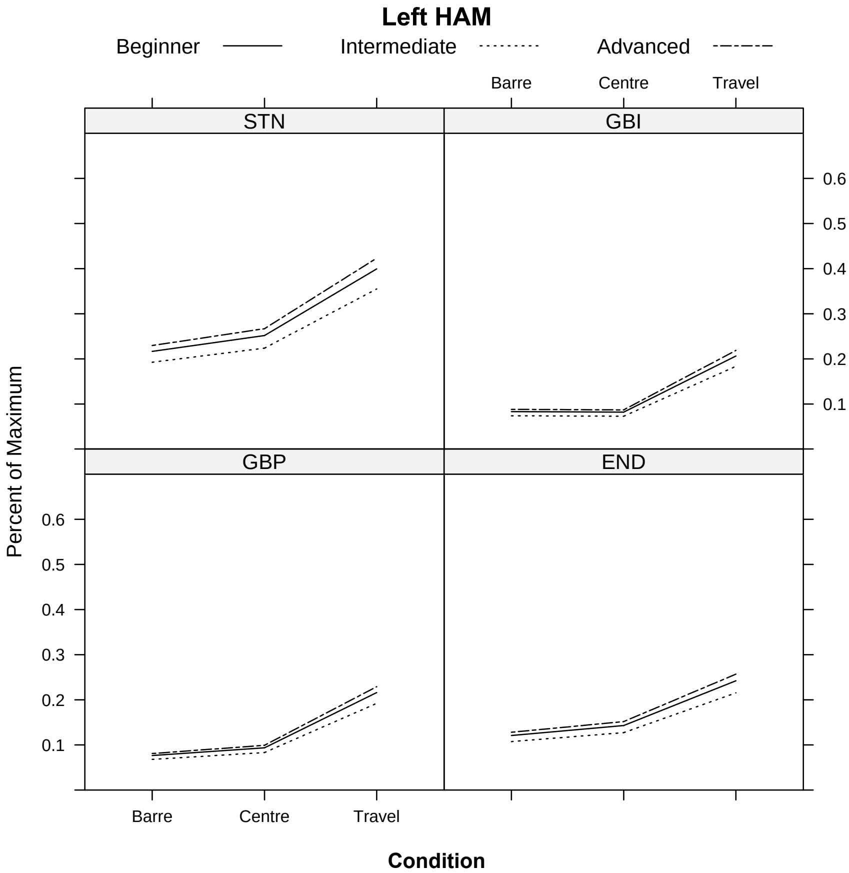

Figure 29. Left HAM by condition by event by level

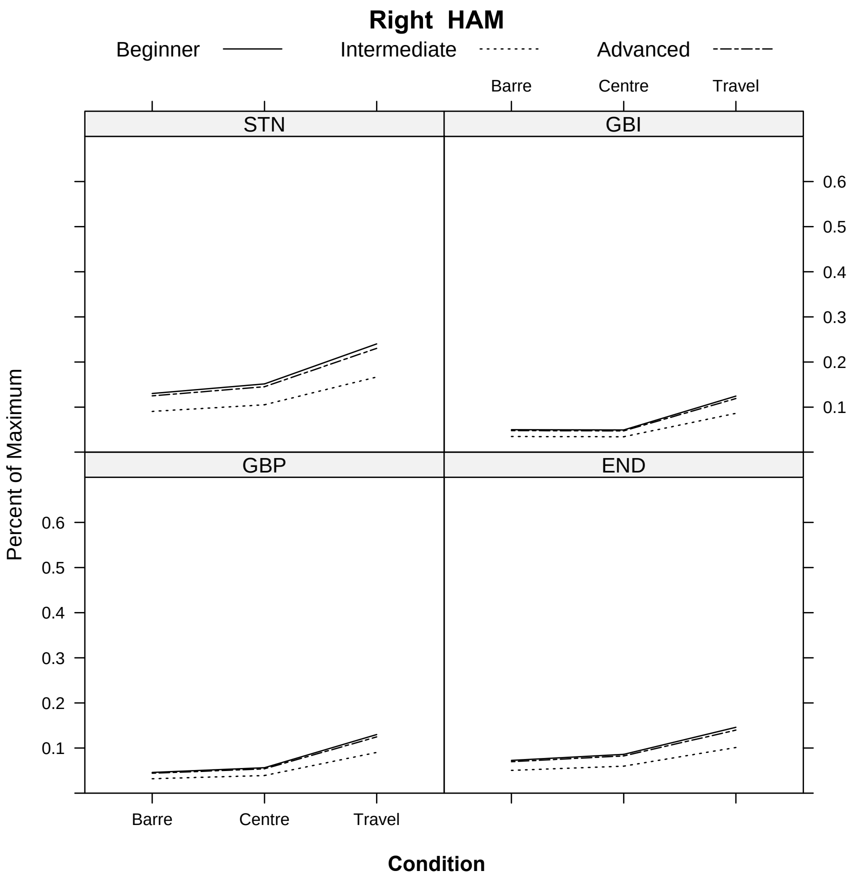

Figure 30. Right HAM by condition by event by level

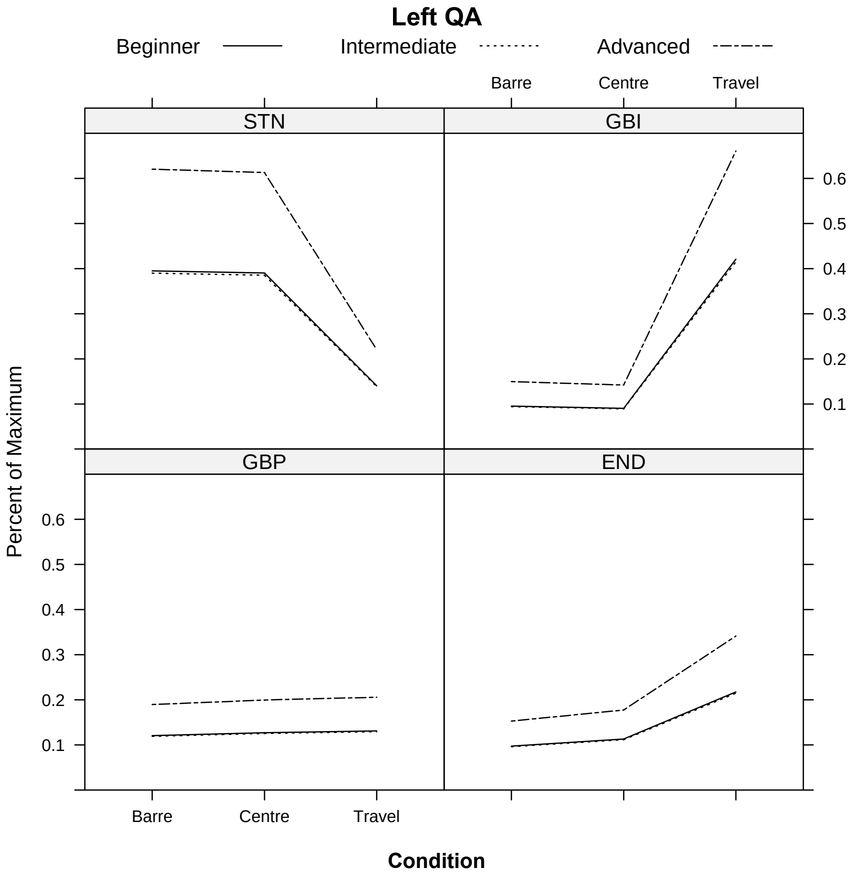

Figure 31. Left QA by condition by event by level

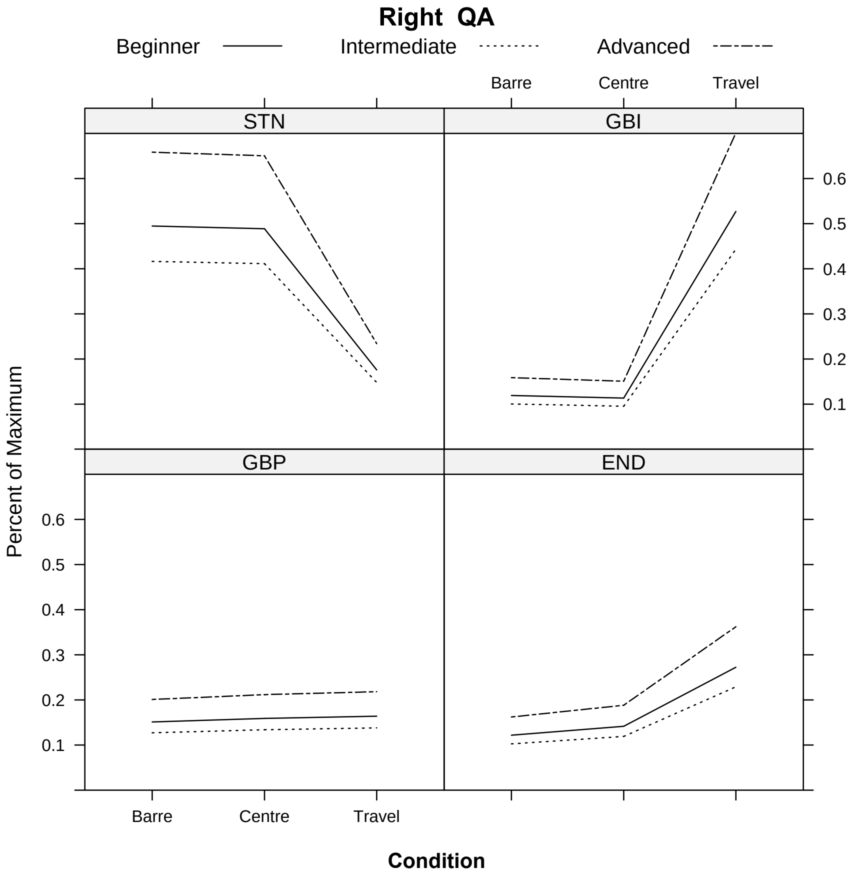

Figure 32. Right QA by condition by event by level

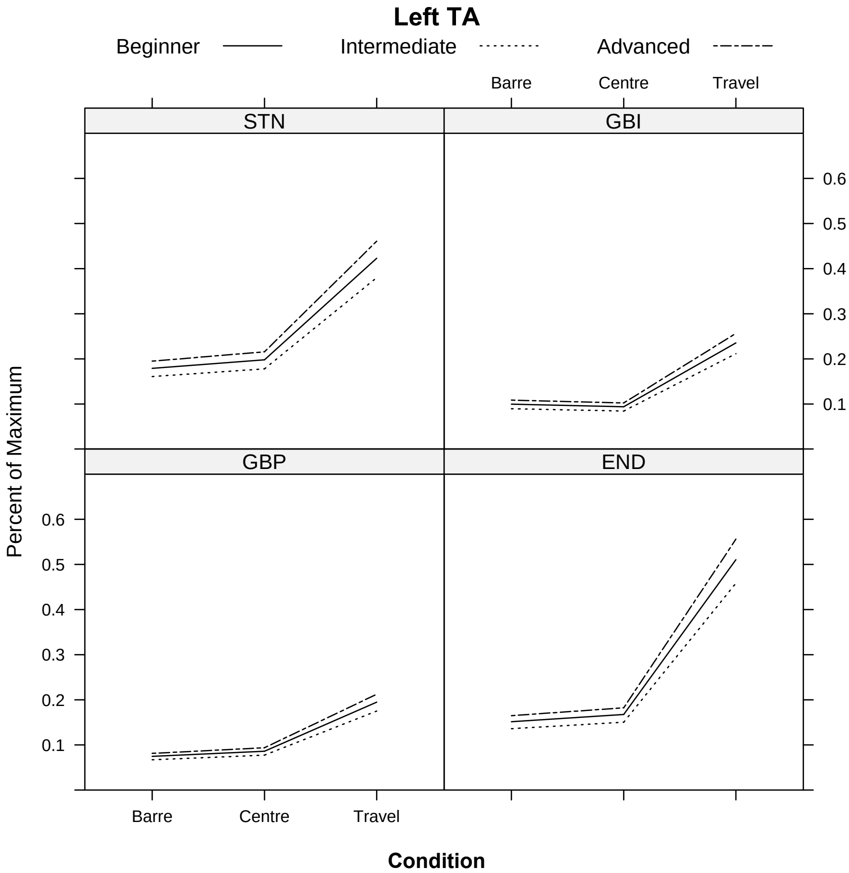

Figure 33. Left TA by condition by event by level

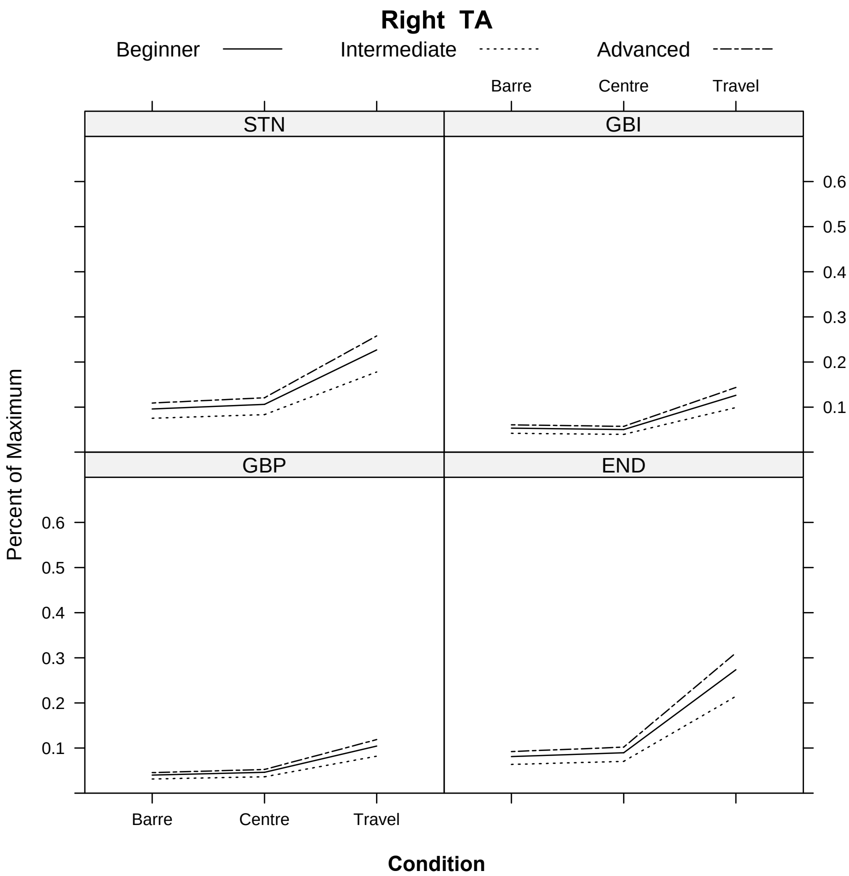

Figure 34. Right TA by condition by event by level

Table 6 shows the p-values for each muscle by condition and by event for all participants. It is clear that there are significant differences between barre and centre, centre and traveling, and barre and traveling for several muscles. Each event (Stance, Initiation, Peak, and End) will be discussed separately.

Table 6. Results of Analysis of Muscle X Condition X Event in all participants

		Events			
Muscle	**Condition**	**Stance**	**Initiation**	**Peak**	**End**
		p-value	**p-value**	**p-value**	**p-value**
ABS	barre to centre	**0.71**	**0.98**	**0.86**	**0.38**
	barre to traveling	0.03	0.03	**0.07**	<.00001
	centre to traveling	**0.06**	<.00001	**0.11**	<.00001
AH	barre to centre	0.01	**0.42**	<.01	0.01
	barre to traveling	<.00001	<.00001	<.00001	<.00001
	centre to traveling	<.01	<.00001	<.00001	<.01
ES	barre to centre	**0.07**	**0.79**	**0.23**	**0.80**
	barre to traveling	<.00001	<.00001	<.00001	**0.16**
	centre to traveling	<.00001	<.00001	<.00001	**0.10**
GA	barre to centre	0.03	**0.55**	0.02	0.04
	barre to traveling	<.00001	<.00001	<.00001	<.00001
	centre to traveling	0.01	<.00001	<.00001	<.01
GM	barre to centre	**0.76**	**0.51**	**0.46**	**0.24**
	barre to traveling	**0.71**	<.00001	<.00001	<.00001
	centre to traveling	**0.50**	<.00001	<.01	<.00001
HAM	barre to centre	**0.25**	**0.91**	**0.12**	**0.20**
	barre to traveling	<.00001	<.00001	<.00001	<.00001
	centre to traveling	<.01	<.00001	<.00001	<.01
QA	barre to centre	**0.92**	**0.69**	**0.69**	**0.25**
	barre to traveling	<.00001	<.00001	**0.53**	<.00001
	centre to traveling	<.00001	<.00001	**0.81**	<.00001
TA	barre to centre	**0.93**	**0.43**	**0.86**	**0.38**
	barre to traveling	0.04	0.04	0.04	<.01
	centre to traveling	0.04	0.03	0.04	0.01

Rectus Abdominus (ABS), Abductor Hallucis (AH), Erector Spinae (ES), Gastrocnemius (GA), Gluteus Maximus (GM), Biceps Femoris (HAM), Quadriceps (QA), and Tibialis Anterior (TA)
Note: The non-significant p-values are in bold.

Table 7 shows the p-values for each muscle by training level. Some muscles seem very impacted by level of training, while others seem unaffected by training. This will be discussed in detail at the end of the Discussion section.

Table 7. Results (p-values) of Analysis of Muscle X Training Level

Muscle	**Beginner to Intermediate**	**Intermediate to Advanced**	**Beginner to Advanced**
	p-value	**p-value**	**p-value**
Abdominals	0.3	0.03	0.12
Abductor Hallucis	<0.01	0.01	<0.01
Erector Spinae	0.01	0.01	0.07
Gastrocnemius	0.2	0.01	0.01
Gluteus Maximus	0.98	0.09	0.26
Hamstrings	0.35	0.07	0.77
Quadriceps	0.63	0.05	0.02
Tibialis Anterior	0.34	0.04	0.11

4.4.2.1 Stance: Muscle x Event x Condition.

In the Stance event, most of the significant differences were found between traveling and the other two conditions. For GM, there were no significant differences between any of the three conditions. For ABS there was a significant difference only between barre and traveling, $p = .03$. There were significant differences for ES, HAM, QA, and TA between barre and traveling, and between centre and traveling. For ES, barre and traveling, and centre and traveling were both significantly different at $p < .00001$. For HAM, barre and traveling were significantly different at $p < .00001$, and centre and traveling at $p < .01$. For QA, barre and traveling, and centre and traveling were both significantly different at $p < .00001$. For TA, barre and traveling, and centre and traveling were both significantly different at $p < .04$. There were significant differences between all three conditions for AH, with barre and centre at $p = .01$, barre and traveling at $p < .00001$, and centre and traveling at $p < .01$. As well, there were significant differences for GA for all three conditions, with barre and centre at $p = .03$, barre and traveling at $p < .00001$, and centre and traveling at $p = .01$.

4.4.2.2 Initiation: Muscle x Event x Condition.

For all muscles tested, there were significant differences in the Initiation event between barre and traveling and between centre and traveling. For the ABS, barre and traveling were significantly different at $p = .03$, and centre and traveling were significantly different at $p < .00001$. For AH, ES, GA, GM, HAM, and QA, both barre and traveling, and centre and traveling were significantly different at $p < .00001$. For TA, barre and traveling were significantly different at $p = .04$, and centre and traveling were significantly different at $p = .03$. There were no significant differences for any muscles in this event for barre and centre.

4.4.2.3 Peak: Muscle x Event x Condition.

As with the Stance event, most of the significant differences in the Peak event were found between traveling and the other two conditions. For ABS and for QA, there were no significant differences between the three conditions. There were significant differences between barre and traveling, and between centre and traveling for ES, $p < .00001$ for both, for GM, $p < .00001$ for barre and traveling and $p < .01$ for centre and traveling, for HAM, $p < .00001$ for both, and for TA, $p = .04$ for both. There were significant differences between all three conditions for AH with barre and centre significant at $p < .01$, barre and traveling at $p < .00001$, and centre and traveling at $p < .00001$, and for GA with barre and centre significant at $p = .02$, barre and traveling at $p < .00001$, and centre and traveling at $p < .00001$.

4.4.2.4 End: Muscle x Event x Condition.

As with the previous events, most of the significant differences in the End event were found between traveling and the other two conditions. For ES, there were no significant differences between any of the three conditions. There were significant differences between barre and traveling, and between centre and traveling for ABS, GM, and QA with $p < .00001$ for both barre and traveling and for centre and traveling. For HAM, barre and traveling were significantly different at $p < .00001$, and centre and traveling were significantly different at $p < .01$. For TA, barre and traveling were significantly different at $p < .01$, and centre and traveling were significantly different at $p = .01$. There were significant differences between all three conditions for AH with barre and centre at $p = .01$, with barre and traveling at $p < .00001$, and with centre and traveling at $p < .01$. For GA there were also significant differences for all three conditions, with barre and centre at $p = .04$, barre and traveling at $p < .00001$, and centre and traveling at $p < .01$.

4.4.3 Discussion.

4.4.3.1 Stance: Muscle x Event x Condition.

With the exception of the GM, all muscles were used differently during the traveling condition than at the barre or in the centre in the Stance event. For ABS, muscle activation was actually at a lower percentage of maximum when traveling than at the barre, but ABS did not differ significantly between barre and centre or between centre and traveling. However, for ES, HAM, and TA, muscle use was at a greater percentage of maximum for traveling than for barre and centre, and these differences were significant. For QA, as with ABS, muscle use was dramatically lower for traveling, and was significantly different from both barre and centre. The only two muscles that demonstrated differences between all three conditions were AH and GA, and activation increased from barre to centre and from centre to traveling. It is interesting to note that the ankle strategy for balancing mechanisms described by Cordo and Nashner (1982) starts with activation of the TA and GA at the moment of loss of equilibrium, and this study was done in natural (parallel) stance. It may be the case that the AH takes over some of the anterior postural adjustment when the legs are in external rotation. Another noteworthy observation is the lower muscle activation of the right GM compared to the left GM in the stance phase, even though no movement initiation has begun. The GM is already favoring the standing (left) leg, in all three conditions. Perhaps the GM is stabilizing the stance hip to accept the full body weight in single-legged balance in preparation for the battement.

4.4.3.2 Initiation: Muscle x Event x Condition.

In the Initiation event, barre and centre had no significant differences for all muscles tested, but traveling was significantly different from the other two conditions for all muscles. The muscles increased activation from stance to initiation, and the change for QA in the traveling condition mirrored the sharp decrease in this muscle in the traveling condition at Stance when compared to barre and centre. Clearly, differences in muscle use between the two conditions (barre and centre) is not demonstrated at the moment of initiation in the grand battement, even though strategies for transferring the weight from two feet to one at the moment of initiation have been demonstrated to be significantly different for barre and centre, as discussed in Section 4.2.2.1, Stance to Initiation in the x-axis. It may the case that upper extremity muscles are involved at the barre to accommodate weight transfer, or that lower extremity and trunk muscles not tested, such as hip adductors, participate at the initiation of weight transfer.

4.4.3.3 Peak: Muscle x Event x Condition.

In the Peak event, the graphs of both ABS and QA appear in the plots as flat lines across the three conditions, meaning there is essentially no difference across conditions in the use of these two muscles at the peak of the battement. As with Stance, ES, HAM, and TA all increased in activation from barre to traveling and from centre to traveling, but did not demonstrate significant differences between barre and centre. And once again, the two muscles demonstrating significant differences between all three conditions are AH and GA, the lower leg muscles that may be contributing to ankle strategy balancing mechanisms, as previously discussed.

4.4.3.4 End: Muscle x Event x Condition.

The only muscle that had no differences between conditions in the End event was ES, appearing as a flat line on the graph. For ABS, GM, HAM, QA, and TA, there are significant differences between barre and traveling and between centre and traveling. Muscle activation levels increased across the three conditions (barre to centre to traveling), although there was no significant difference between barre and centre. As in both Stance and Peak, both AH and GA showed significant differences for all three conditions. Clearly, these two lower leg muscles are the muscles that change activation levels from barre to centre to traveling, increasing with each change of difficulty level regarding balancing strategies. The graphs of the right and left AH exhibit pronounced increases in this event, from one condition to the next, particularly for the left (standing) leg.

4.4.3.5 Overview of each muscle for all conditions.

While the ABS demonstrated changes primarily in the traveling condition of the Initiation and End events, it was surprising to see how little change there was across the three conditions for Peak. One might think that at the peak of the battement, abdominals would increase activity to assist in stabilizing the trunk, but this was not really the case. The ES appeared as an inverse image to the ABS, with more activity in traveling for Stance and Peak, but not for Initiation and End. It may be that the ABS and ES act in a cooperative manner over the four events, with ABS increasing activation across conditions for Initiation and End, while ES has the opposite pattern, increasing activation across conditions for Stance and Peak. Dance educators may place such a high emphasis on abdominal use in dance training that the motor control of multiple trunk muscles is overlooked in cuing and instruction.

The other surprising result was the lack of GM activity on the right (gesture) leg throughout the movement, with values staying below 20% of maximum for all events, and below 10% for Peak. While some have theorized that the GM needs to shut off at Peak to accommodate full hip flexion, others have suggested that it remains active for external rotation. In the study by Bronner and Ojofeitimi (2011), external rotation diminished at the peak of grand battement devant in elite dancers. In this study, the gesture leg GM was quiet at Peak, and in fact, was at low levels throughout the movement. On the standing (left) side, however, there was more GM activity, particularly in traveling at Initiation and End. The left GM demonstrated its highest activity at the barre and centre in Stance, before any movement initiation began. Similarly the right (gesture) leg HAM was fairly quiet throughout the movement (below 15%), with highest levels in Stance; on the left (standing) leg, activity was greater than the right HAM in all events, and also highest in Stance.

The QA demonstrated low levels of activity in Stance during traveling (the moment of shifting weight onto the left leg in preparation of the battement), a significant increase at Initiation, a drop back down to Stance levels at Peak, and another rise with traveling at End. It is probable that the high activity of the QA at Initiation relates to stabilization on the standing leg, which is in plié in the traveling condition. Surprisingly, at barre and centre, the greatest QA activity for both legs was in the Stance event, much higher than at any other event, and in comparison to other muscles. One might wonder why dancers are using such high levels of QA activity (40-60%) just standing in first position. The quadriceps activity of 40%-60% in Stance is most likely not related to antagonistic activation, as the hamstrings are only at 10%-20% during the Stance event. It is possible that the high levels of quadriceps activity during Stance relate to a conscious effort by the dancer to engage the quadriceps. In traditional dance training, some teachers cue dancers to “lift the kneecaps” or “tighten the front of the thighs” as they believe it can increase both stability and strength. It may be that dancers are being cued unnecessarily to overexert in the quadriceps muscles in standing postures, even though much lower levels of activation are needed for dynamic movement, as shown in Figures 31 and 32.

One might anticipate greater difference in the TA between barre and centre, due to its importance in postural reflexes (Cordo & Nashner, 1982), but this was not the case. As mentioned previously, the two muscles that consistently demonstrated differences for almost all conditions and events were the AH and the GA. As noted earlier, the balancing mechanism described by Cordo and Nashner (1982) starts with activation of the TA and GA at the moment of loss of equilibrium in natural (parallel) stance. It may be the case that with external rotation, the TA moves to a lateral (frontal plane) position with respect to the movement, and the AH takes over some of the anterior postural adjustment. While dancers do strength work for other small muscles of the foot, the AH might be a muscle of consideration for further training of the deep intrinsic muscles of the foot.

4.4.3.6 Training levels: Level x Side x Muscle.

First, it should be noted that the pattern of change for all muscles from barre to centre to traveling is similar for all three levels of training in this study. For example, looking at the right GA, regardless of level of training, muscle use was lowest at the barre, increased for centre practice, and increased more for the traveling condition. What is different between the three training levels is amplitude, or percentage of maximum used. For almost all muscles, for all events, the intermediate dancers used the least percentage of maximum, the advanced dancers used the highest percentage of maximum, and the beginners were in between. It might be that dancers go through a transitional phase in which they diminish muscle use while trying to find more efficient motor patterns and eliminate unnecessary tension, and then once they are organized, they begin to work at higher levels of muscle activation again. It would require a longitudinal study to answer this question fully. Exceptions to this pattern were right (gesture) ABS, AH, and right (gesture) GM where the beginners use a higher percentage than the advanced dancers; the ES and HAM, where beginners and advanced dancers are almost identical; and left QA where beginners and intermediate dancers are almost identical. It may be that the beginners use a higher percentage of maximum for right ABS and right GM due to attention to the gesture leg as opposed to the standing leg, whereas advanced dancers may put more focus on the supporting leg to achieve the task, perhaps due to cueing from teachers as well as enhanced balance. Further research might shed some light on this hypothesis.

CHAPTER FIVE

SUMMARY

[portions of this chapter have been published in *Medical Problems of Performing Artists]*

Krasnow, D., Ambegaonkar, J. P., Wilmerding, M. V., Stecyk, S., Koutedakis, Y., & Wyon, M. (2012). Electromyographic Comparison of Grand Battement Devant at the Barre, in the Centre, and Traveling. *Medical Problems of Performing Artists, 27*(3), pp. 143-155*.*

Krasnow, D., Wilmerding, M. V., Stecyk, S., Wyon, M., & Koutedakis Y. (2012). Examination of weight transfer strategies during the execution of grand battement devant at the barre, in the centre, and traveling. *Medical Problems of Performing Artists, 27*(2), pp. 74-84*.*

5.1 General Conclusions

The scope of this research study was multi-layered and complex. It considered three conditions for comparison, barre, centre, and traveling, which is unique in the dance science literature. It examined dance movement using both motion analysis and electromyography. It compared dancers in three levels of dance training, beginner, intermediate and advanced. And finally, the subject pool was relatively large for a dance study.

The dance science literature supports each of these aspects in segments. Past studies compared dance movements at the barre and in the centre (Ryman & Ranney, 1978/79; Kadel & Couillandre, 2007; Wieczorek, Casebolt, Lambert, & Kwon, 2007; Wilmerding, Heyward, King, Fiedler, Stidley, Pett, & Evans, 2001), but no dance study has added the traveling component to the inquiry. The past research suggests that barre and centre differ significantly in both weight transfer strategies and muscle activation. In previous studies, dancers have shifted less towards the supporting leg at the barre than in the centre, and certain muscles of postural support and balance fail to activate at the barre.

The use of electromyography has been confusing in the dance science literature. The majority of studies focus on muscle onset times rather than amplitude, and no standardised method to normalise sEMG data has been developed (Ferland et al., 1983; Harley et al., 2002; Lepelley et al., 2006; Ryman et al., 1978/9; Simpson et al., 1996; Simpson et al., 1997; Trepman et al., 1994; Trepman et al., 1998; Wilmerding et al., 2001). This lack leaves a gap in the procedural methodology for dance science research.

There is also ambiguity in the literature surrounding the issue of differences between dancers of various training levels. Generally it is agreed that advanced dancers have superior motor strategies, but then there are instances in which advanced dancers do not surpass beginners. It is proposed that these are situations in which aesthetic issues override skill, such as body line taking precedent over jump height.

The issue of individual variation has become a source of growing controversy in the dance science research field, with researchers such as Chatfield (2003) suggesting that dance research should limit itself to within-subject design, and avoid group means. However, this method is not valid for single testing studies (Barlow, Nock, & Hersen, 2008), which suggests that group design for single session testing is still the best choice, but implies that larger subject pools are essential. This presents difficulty for the dance science community who often do not have access to large numbers of dancers. Nearly half of the studies in the literature have less than 10 subjects.

The studies in the dance science literature suggest that dance pedagogy is not always reflective of best biomechanical practice, nor does it follow what advanced dancers do in practice (Buckman, 1974; Dozzi, 1989; Laws, 1998; Laws & Lee, 1989; Ryman, 1978). Studies that can shed light on how we might improve dance training methods by attending to biomechanics, and studies on the most advanced dancers could enhance not only pedagogical methods but potentially injury prevention and rehabilitation as well.

This study attempted to address several of the issues presented in the dance science literature. It systematically examined, through both kinematics and electromyography, how barre, centre, and traveling might differ with respect to a familiar movement in many dance forms, the grand battement devant. This movement was selected for this study not only because it is familiar to most dancers, but also because it translates easily to all three conditions, and there is previous research discussing this movement.

After reviewing the dance literature, it became clear that it was crucial to develop a valid method of normalising sEMG data, in order to compare muscle amplitudes across subjects. This task became a major component of the study, the development and testing of a dance-specific portable anchored dynamometer, and required an extensive search of the sports science literature using sEMG data.

Relying on the previous work of several sports researchers (Agre, Magness, Hull, Wright, Baxter, Patterson, & Stradel,1987; Andrews, Thomas, & Bohannon, 1996; Bohannon, 2009; Bolgla, Malone, Umberger, & Uhl, 2010; Burden, 2010), a PAD was developed that satisfies the criteria from the sports science literature and is dance-specific.

It is common in dance science research to look only at advanced dancers, or to compare beginner or non-dancers to advanced dancers. The addition of intermediate dancers to this study offered insight as to what transitional steps dancers take in developing from early training to the highest levels of skill. This was another unusual decision in the design of this research study.

The subject pool of 40 dancers was an important feature of this research, and was undertaken so that there was a robust number for statistical analyses, in spite of individual variation demonstrated in the literature. It allowed for having three training level groups, and permitted broader generalisation of results than single-subject design can achieve.

There were four hypotheses proposed in this study. The first hypothesis was that weight shift in the three conditions (that is, transfer of weight from two feet to one foot for the barre and centre conditions, and from one foot to the other foot in traveling), would differ significantly during the three conditions. The second hypothesis was that weight shift in the three conditions would differ significantly between dancers of various training levels. The third hypothesis was that utilisation of the trunk and lower extremity muscles would differ significantly during the three conditions. The fourth hypothesis was that utilisation of the trunk and lower extremity muscles would differ significantly between dancers of various training levels. Results of the study supported hypotheses 1, 3, and 4, but not hypothesis 2.

In this study, kinematic results examining weight transfer demonstrated significance for the main effect of condition, and for almost all intervals for all conditions. However, there were no significant effects for training level, or for condition by training interactions. In general, for lateral weight transfer dancers shift further to the supporting leg in the centre than at the barre, for all variables considered, and shift the least in the traveling condition. For sagittal weight transfer, no overall pattern between centre and barre can be stated, as it varies from interval to interval, but the three conditions were significantly different. Additionally, there were significant differences between the movements of the body regions (pelvis, upper trunk, full trunk, and centre of mass), with dancers exhibiting a variety of strategies for organizing these body regions in the three conditions and during the intervals (stance to initiation, initiation to peak, and peak to end). This suggests that deciding on one variable to study weight transfer would mask the inherent complexity of weight shift strategies.

This study also provides useful information about important differences in muscle activation patterns between barre, centre, and traveling conditions, as well as providing insights into aspects of muscle activation within each condition. The muscles demonstrating significance differences consistently between barre and centre, centre and traveling, and barre and traveling for all events were the abductor hallucis and the gastrocnemius, similar to the ankle strategy suggested in the motor control literature (Cordo & Nashner, 1982). Differences in training levels clearly exist in the EMG results in this study. Overall, intermediate dancers use the lowest percentages of maximum muscle activation for all conditions during the grand battement devant, with advanced dancers using the highest percentages of maximum. Previous studies have demonstrated mixed results concerning muscle use in advanced and novice dancers, and this study provides additional information about training level differences.

The results of this study and previous research suggest that dance classes devoting an inordinate amount of time to barre work may not develop appropriate strategies for unsupported and traveling movement (Nichols, 1979; Wilmerding, Heyward, King, Fiedler, Stidley, Pett, & Evans, 2001; Wilmerding & Krasnow, 2011). In particular, this study indicates that there are differences between barre and centre, and even greater differences in the traveling condition, in both muscle activation levels and weight transfer strategies. By overemphasizing the barre and centre portions of training, dancers may be disadvantaged in terms of the skills and strategies necessary for elite performance and the execution of complex choreography. It is recommended that dance training and injury rehabilitation consider the importance of allocating sufficient time to each of the three conditions, barre, centre, and traveling, to ensure development of varied and appropriate motor strategies for weight transfer and muscle activation in dance practice. This could potentially reduce injury incidence due to factors such as overuse and fatigue (Koutedakis, 2000; Koutedakis, Owolabi, & Apostolos, 2000), and loss of balance and control (Koutedakis & Jamurtas, 2004). It is also recommended that dance educators examine pedagogical methods and cueing to see if there is potential for improvement based on what we now know from biomechanics and the study of advanced dancers.

5.2 Limitations of the Study

The following elements identify uncontrollable factors that limited the design and results of the study: (a) motivation of the participants in the testing sessions, (b) the limited validity of the results for male dancers, as there were no male volunteers, and (c) the limited validity of results for larger dance populations, because the study was done in the Los Angeles, California area with dancers over 18 years of age.

5.3 Delimitations of the Study

The study was further limited by the following design choices and practical considerations:

1. The study targeted dancers with ballet and/or modern background, but many had additional training in other dance forms.
2. Sample size was restricted to 40 participants.
3. Electromyography data collection was limited to eight muscles bilaterally, and did not include other possibly relevant muscles, due to restrictions in the EMG equipment.
4. Movement trials were done with the right leg as the gesture leg for all trials.

5.4 Recommendations for future research

The development of a dance-specific portable anchored dynamometer was crucial to this study, in order to compare muscle amplitudes across participants. There is currently no standardized methodology in dance research for normalization of EMG data. It is recommended that future dance research employ this apparatus for EMG data collection, to provide a better understanding of muscle activation patterns and muscle amplitudes across participants. The PAD developed in this study was tested in single sessions only. In order to use this apparatus for intervention studies, it needs to be tested for reliability across multiple sessions.

In this study, the main weight transfer differences were demonstrated in the frontal plane, due to the use of 1st position. First position was used at the barre and in the centre, as it allowed for a more direct comparison between the three conditions for this particular movement, the grand battement devant. In 5th position, it is likely that weight transfer increases in the sagittal plane, but diminishes in the frontal plane. It is recommended that a similar study design using 5th position be employed comparing barre, centre and traveling, with a dance movement that has a traveling equivalent from 5th position, such as sissonne or assemblé.

It was observed that activation in the muscles tested in this study did not differ between barre and centre at the moment of initiation, even though weight transfer strategies were significantly different. The two muscle groups not tested that might account for this result are the hip adductors / abductors, and the upper extremity muscles. For example, it may be that the hand holding the barre participates in weight transfer by pulling the body towards the barre. Future research could broaden the scope of muscles tested to gain further insight.

Finally, the limitation of the study to all female dancers should be addressed in future research. To date, studies have demonstrated inconsistent results regarding gender differences (Bartolomeo, Sette, Sloten, & Albisetti, 2007; Bronner & Ojofeitimi, 2006; Mayers, Agraharasamakulam, Ojofeitimi, & Bronner, 2005; Orishimo, Kremenic, Pappas, Hagins, & Liederbach, 2009; Wilmerding, Gurney, & Torres, 2003), and this aspect of dancers should be further explored.

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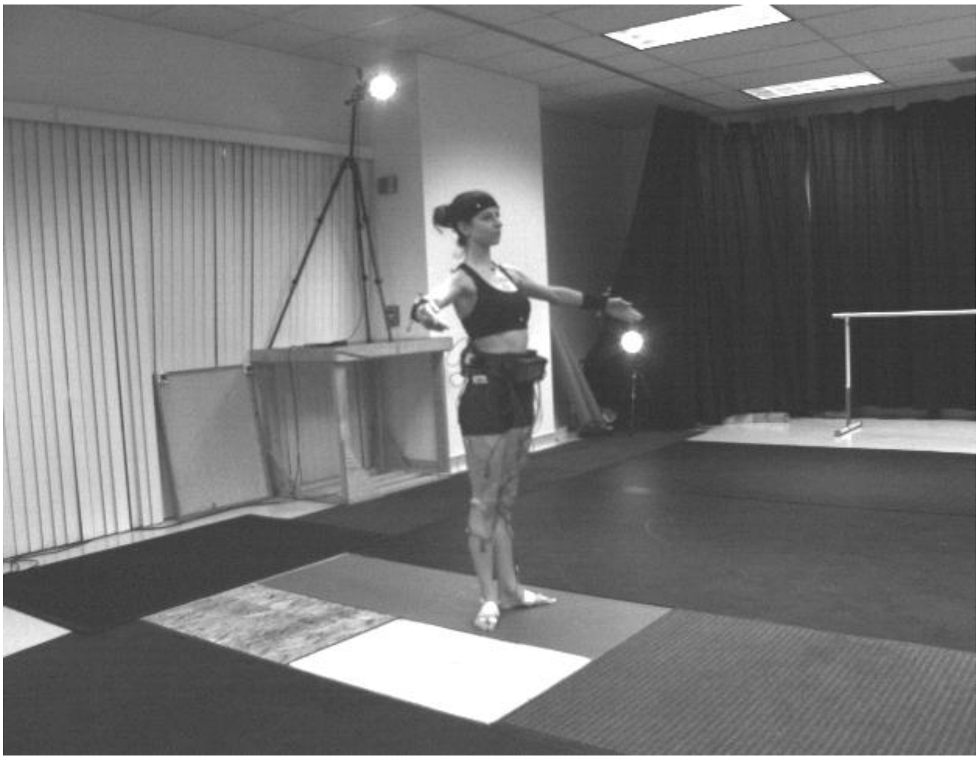
Appendix A
Photographs of the three conditions and the events

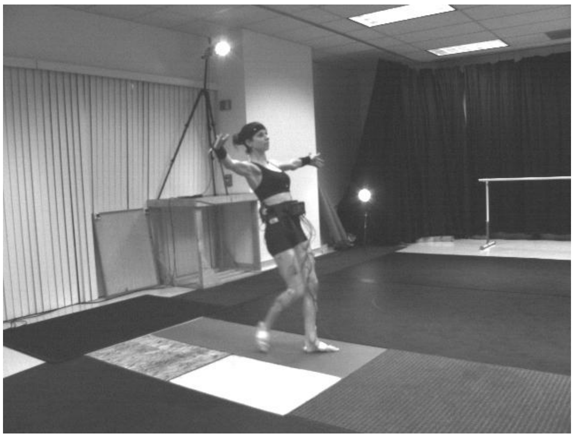
Grand battement at the barre, Stance (and End) Event

Grand battement at the barre, Peak Event

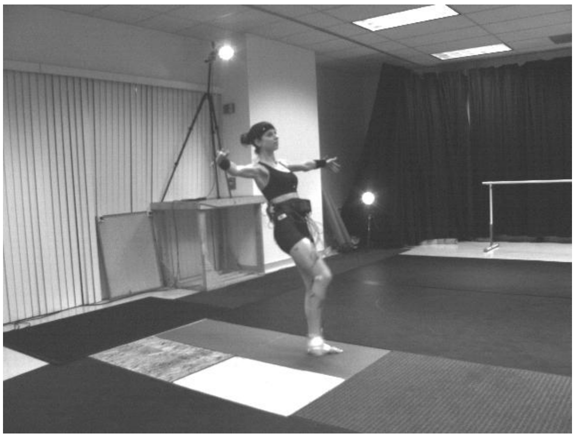


Grand battement in the centre, Stance (and End) Event

Grand battement in the centre, Peak Event



Grand battement traveling,
Stance Event



Grand battement traveling,
Initiation Event

Grand battement traveling,
Peak Event

Grand battement traveling,
End Event

APPENDIX B

CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

Project Title: Grand Battement Devant at Barre, Centre, and in Motion

PARTICIPANT INFORMED CONSENT FORM

Introduction:

This study, conducted by Shane Stecyk, PhD, and his research team, is designed to compare the way your body moves while executing a Grand Battement Devant in three different situations.

Description of Research:

This research will add to our understanding of how the body moves during the execution of a grand battement devant, and if the body moves differently during the three situations: barre, center work, and traveling across the floor. This research may also help us determine appropriate progressions for warm-up and teaching. You will be asked to come to the Biomechanics Lab to perform the Grand Battement Devant 25 times. After Informed Consent is given, you will complete a Modified Par Q form asking about your current health status, and a questionnaire about your previous dance experience. Various measurements will be taken (i. e., height, weight, leg length, etc.) 1” X ½” electrodes (pieces of plastic) and ½” X ½” markers (balls that reflect light) will be attached to your joints and muscles with double sided tape. The electrodes measure the amount of muscle activity and the markers are used to measure angles of various joints. You will be tested using a dynamometer anchoring system to determine the maximum voluntary contractions (MVCs) of the muscles. You will push against a stationary object for five seconds, three times, with 30-second rests in between, for each muscle. After these MVC tests, a force plate, cameras and a computer will record your efforts. It is expected that you will be in the lab for a total of three hours. You will be provided with breaks as requested.

Subject Information and Risks:

Risks are minimal as this is a very common dance movement. Risks include fatigue, muscle soreness, strains and sprains. Risks will be minimized because you will complete an activity questionnaire to determine if this activity is appropriate for you, you will complete your own warm-up, and you may withdraw from the study at anytime, without consequence. You may experience irritation or an allergic reaction to the tape. If an injury occurs, you will be referred to the health center on campus or to your own physician.

Confidentiality & Final Disposition of Data:

All information collected during this project will be held in strict confidence as required by law. Confidentiality will be maintained by using codes rather than personal identifying information. The data and copies of the consent form will be kept in a locked cabinet at the investigator’s office. The study results may be published in scientific journals or presented at scientific meetings but the names or identity of participants will not be made known. Identifiable data will be destroyed upon disposition of data.

Benefit of Participation:

You will not receive monetary compensation for participation in this study. However, the results may enable us to make recommendations regarding the training of artists and the organization of dance class.

Concerns:

If you wish to voice concern about the research, you may direct your questions to Research and Sponsored Projects, 18111 Nordhoff Street, California State University, Northridge, Northridge, CA, 91330-8232, or phone 818-677-2901. If you have specific questions about the study you may contact Dr. Shane Stecyk at 18111 Nordhoff Street, Northridge, CA 91330-8287 or by phone at (818)372-4738.

Voluntary Participation:

You should understand that your approval to participate in this study is completely voluntary, and you may decline to participate or withdraw from the study at any time without jeopardy. Likewise the researcher may cancel this study at any time. A copy of your informed consent will be stored in a locked filing cabinet and you will be given a copy of this informed consent for your records.

Videotaping:

During the course of the project participants will be videotaped. Your initials here ______ signify your consent to be videotaped. All tapes collected as part of this project will be kept on file by the researcher at the conclusion of the study.

I have read the above and understand the conditions for participation in the described study. I understand that in no way does signing this form remove any of my legal rights nor does it relieve the investigators, sponsors or involved institutions from their legal and professional duties. I give consent to participate in the study.

Participant's Name ____
(please print) Last First MI

Street Address ____

City ______________________________ State _________ Zip _________

Subject Signature:

Signature ____________________________________ Date ______________

Witness Signature:

Witness/P.I. Signature _________________________ Date ______________

If you have signed this form, please return one copy in an envelope to:

Dr. Stecyk
Department of Kinesiology
California State University, Northridge
18111 Nordhoff St
Northridge, CA 91330-8287

Keep one copy of this form for your records.

CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

EXPERIMENTAL SUBJECTS

BILL OF RIGHTS

The rights below are the rights of every person who is asked to be in a research study. As an experimental subject I have the following rights:

1. To be told what the study is trying to find out,

2. To be told what will happen to me and whether any of the procedures, drugs, or devices is different from what would be used in standard practice,

3. To be told about frequent and/or important risks, side effects or discomforts of the things that will happen to me for research purposes,

4. To be told if I can expect any benefit from participating, and, if so, what the benefit might be,

5. To be told the other choices I have and how they may be better or worse than being in the study,

6. To be allowed to ask any questions concerning the study both before agreeing to be involved and during the course of the study,

7. To be told what sort of medical treatment (if needed) is available if any complications arise,

8. To refuse to participate at all or to change my mind about participation after the study is started. This decision will not affect my right to receive the care I would receive if I were not in the study,

9. To receive a copy of the signed consent form,

10. To be free of pressure when considering whether I wish to agree to be in the study.

If I have other questions I should ask the researcher or the research assistant, or contact Research and Sponsored Projects, California State University, Northridge, 18111 Nordhoff Street, Northridge, CA 91330-8232, or phone (818)677-2901.

X____

Signature of Subject Date

APPENDIX C

Physical Activity Readiness Questionnaire (PAR-Q)

This form was modified from Clarkson University Fitness Center PAR-Q-www.clarkson.edu/fitness/parq.doc

PAR-Q is designed to help you help yourself. Many health benefits are associated with regular exercise, and the completion of PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life.

For most people, physical activity should not pose any problems or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should seek medical advice concerning the type of activity most suitable for them.

Common sense is your best guide in answering these few questions. Please read the carefully and check YES or NO opposite the question if it applies to you. If yes, please explain.

YES NO

____ ____1. Has your doctor ever said you have heart trouble?
Yes, ____

____ ____ 2. Do you frequently have pains in your heart and chest?
Yes, ____

____ ____3. Do you often feel fain or have spells of severe dizziness?
Yes, ____

____ ____4. Has a doctor ever said your blood pressure was too high?
Yes, ____

____ ____5. Has your doctor ever told you that you have a bone or joint problem(s), such as arthritis, back pain, numbness, etc. that would not allow you to follow an activity program even if you wanted to?
Yes, ____

____ ____6. Is there any other medical condition, not mentioned here, that would not allow you to follow an activity program even if you wanted to?
Yes, ____

YES NO

____ ____7. Are you over age 60 and not accustomed to vigorous exercise?
Yes,

____ ____8. Are you currently taking any medications that would not allow you to follow an activity program even if you wanted to? If YES, please specify.
Yes,

If you answered NO to all questions above, it gives a general indication that you may participate in physical activity. The fact that you answered NO to the above questions, is no guarantee that you will have a normal response to exercise. If you answered Yes to any of the above questions, we recommend that you see a physician before participating in physical activity.

Print Name	Signature	Date

APPENDIX D

Subject Information Sheet

NAME ______________________________ **Date** ______________________

Group: Advanced Intermediate Novice

Age ___ **years** **Phone number** _______________ **Email** _______________

Address

____

Exclusion Criteria

1. Did you answer "Yes" to any of the questions on the PAR-Q? Yes No

Anthropometric Measurements-

Mass-___________kg	Height- _______________cm
Inter ASIS distance- _______cm	Leg length- L-_____cm R- ____cm
Knee width- L-____cm R- _____cm	Ankle width- L- ____cm R- ____cm
Shld Offset- L- ____cm R- ____cm	Elbow width- L- ____cm R- ___cm
Wrist width- L- ____cm R- ____cm	Hand width- L- ____cm R- ____cm

Dance experience:

1. How many years of dance training do you have? ___________ years
2. What are the primary forms you have studied (e.g. ballet, modern, jazz, etc.)?
   ____
   ____
3. How many times do you take dance class per week?
   ____
4. How many times do you rehearse in choreography per week?
   ____
5. How many hours do you rehearse per week?
   ____
6. Have you performed in a setting in which you have been paid for your services?
   Yes ______ No ________ If yes, please describe:
   ____
   ____
7. What other training do you do on a regular basis? (ie. Yoga, Pilates, Gyrotonic, running, other conditioning forms, other sports activities)
   ____
   ____
   ____
   ____

8. Do you have pain when you dance? Yes No
9. What movements cause pain during dance classes or rehearsals?

10. Do you have any current dance injuries that affect your dancing? Yes No

If so, describe: